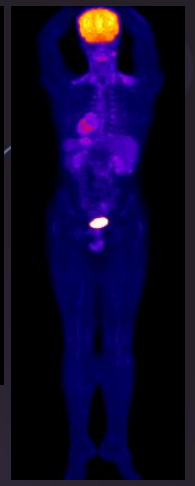

GATE

: Monte Carlo Simulation platform based on GEANT4

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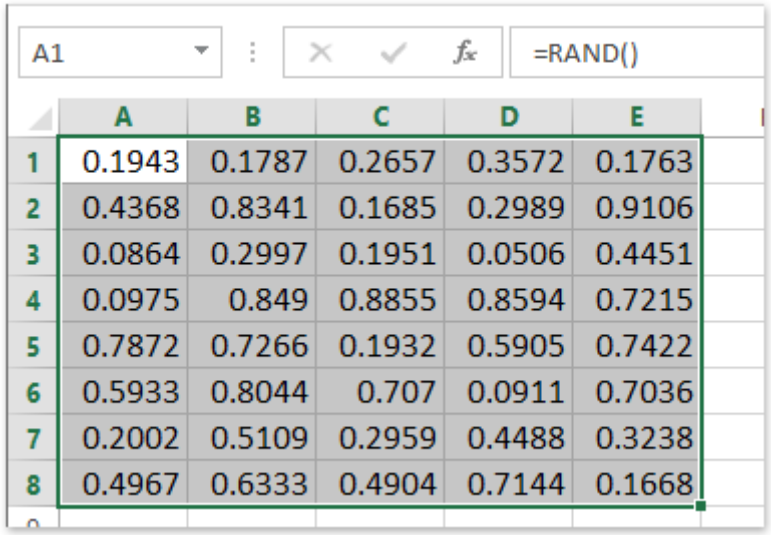
Contents

I. Introduction of Monte-Carlo Simulation

Random Number – Core of MC

- Computer-generated numbers
  - 'Pseudo' random number
  - Middle square, linear-congruent method, moultiply-with-carry(MWC)
  - rand() function in MATLAB
    - Numbers between 0 and 1
    - Random, but also uniform

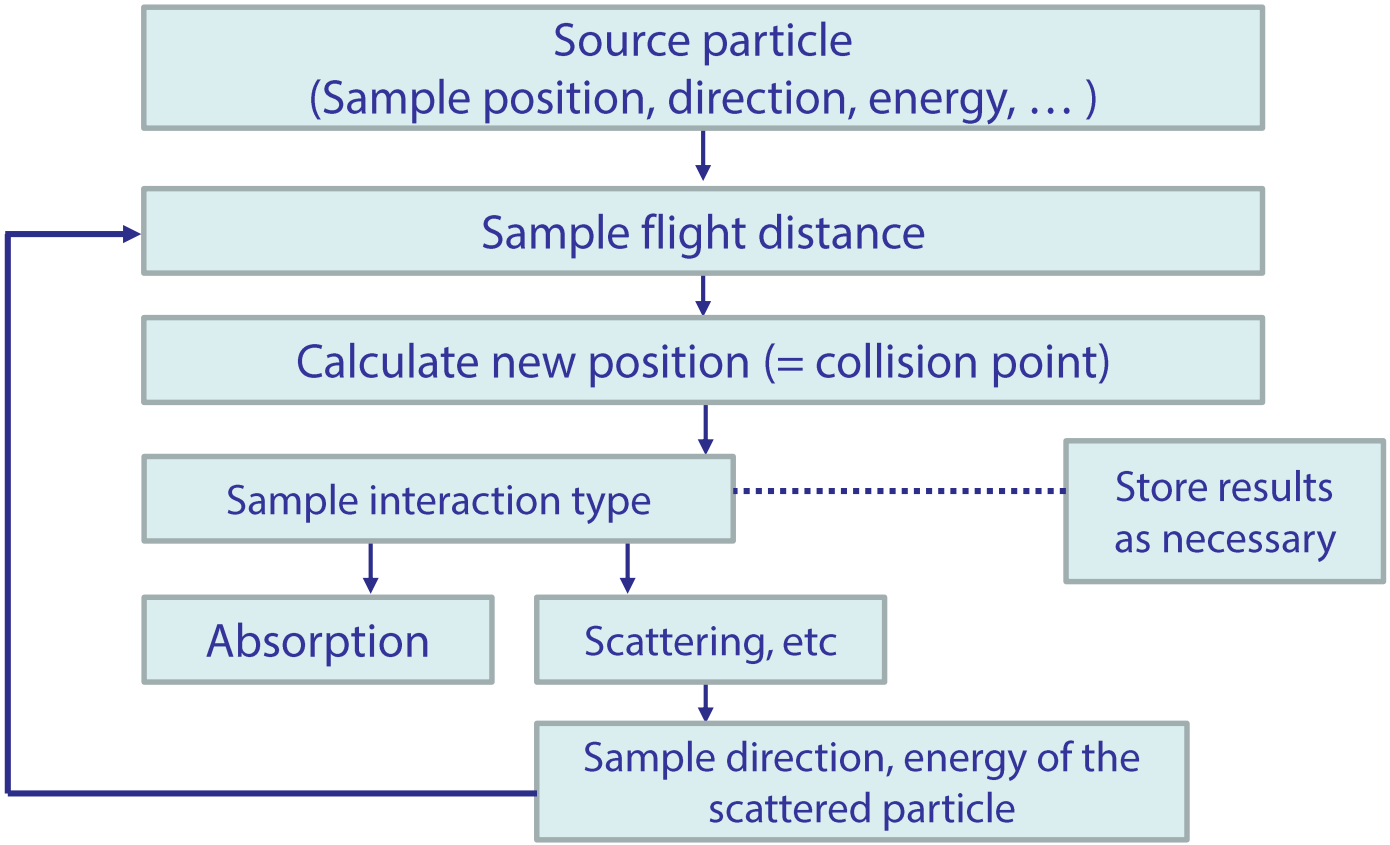


	A	B	C	D	E
1	0.1943	0.1787	0.2657	0.3572	0.1763
2	0.4368	0.8341	0.1685	0.2989	0.9106
3	0.0864	0.2997	0.1951	0.0506	0.4451
4	0.0975	0.849	0.8855	0.8594	0.7215
5	0.7872	0.7266	0.1932	0.5905	0.7422
6	0.5933	0.8044	0.707	0.0911	0.7036
7	0.2002	0.5109	0.2959	0.4488	0.3238
8	0.4967	0.6333	0.4904	0.7144	0.1668

Table of random number between 0 and 1

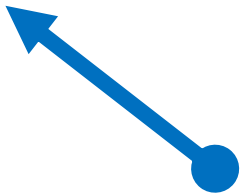
Flow of Radiation Transport Simulation

- Use physics models and cross section data to sample direction, flight distance, etc.



Flow of Radiation Transport Simulation

1. Sample a source particle:
   - Position
   - Direction
   - Energy
   - Time (=0, default)
   - Weight (=1, default)



(x_0, y_0, z_0)
(u, v, w)
E_0
T_0
W_0

2. Sample the distance to the first interaction point, or the flight distance(l), using the total cross section.

$$l = (-\ln \xi) \times \lambda$$

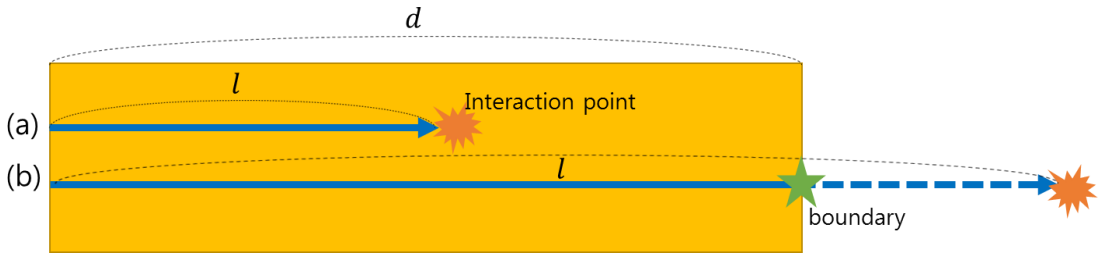
Where ξ is a random number and λ is mean free path.

Flow of Radiation Transport Simulation

3. Check whether the interaction point is within the same region or not.

- Compare the flight distance (l) with the distance to the region boundary (d)
  - (a) If $l < d$, move the particle to the interaction point
  - (b) If $l \geq d$, move the particle to the boundary.

(d)



  - If the new region is outside the system of interest, stop following this particle and produce a new particle.
  - If the new region is inside the system of interest, repeat Step 2 in the new region.

- A charged particle, such as electron or proton, changes its direction and energy while moving to the interaction point and, therefore, the treatment becomes more complicated.

Flow of Radiation Transport Simulation

4. Sample the type of interaction.

- The type of interaction is sampled using discrete-type probability distribution functions.
- Photoelectric effect, Compton scattering or pair production is selected for photon.
    - Example
        - Photoelectric effect (absorption): 30%
        - Compton scattering: 50%
        - Pair production: 20%

5. Sample the energy and direction of the scattered particle at the interaction point using the differential cross section of the interaction.

Flow of Radiation Transport Simulation

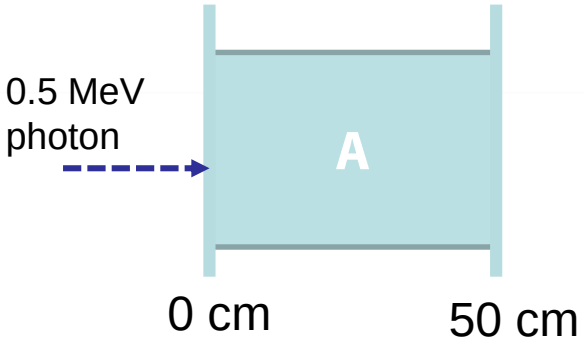
6. Store any information of interest when a particle reaches to the region of interest:
    - Type of particle and its energy
    - Energy imparted to the medium.

7. Terminate following the particle if
    - The particle is absorbed
    - The particle escapes from the system, or
    - The particle energy becomes below the cut-off energy.

8. A 'history' is defined as the whole process from the production of a source particle until its termination.
    - Information of interest can be obtained by repeating many histories.

Flow of Radiation Transport Simulation

- Consider uniform medium, A, of 50cm thickness.



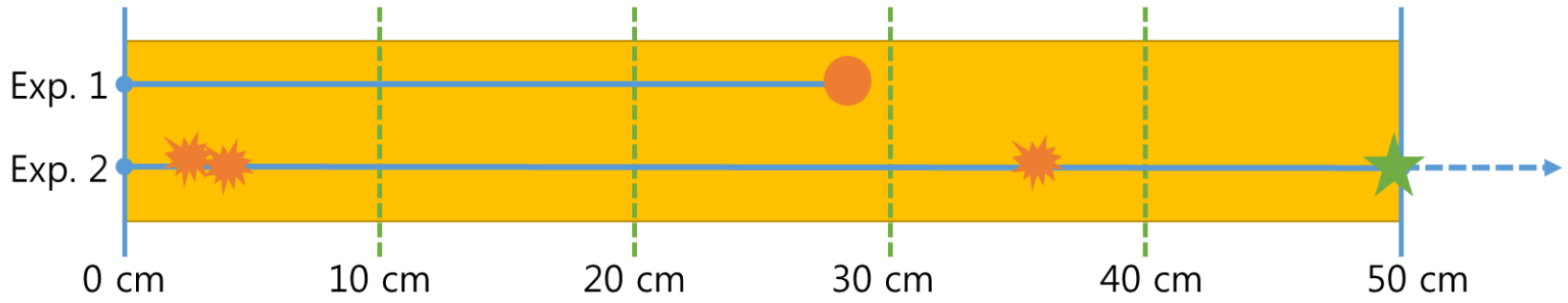
- Suppose that
  - 0.5 MeV photons enter the system from the left end,
  - The mean free path (λ) is 20 cm
  - The ratio of the photoelectric effect and Compton scattering is 1:1
  - A scattered photon does not change its energy or direction.

- Starting from an arbitrary random number from a random number table, follow the photons and ***count the number of photons that penetrate the layer.***

Flow of Radiation Transport Simulation

$\xi < 0.5$

No.	d (cm)	ξ	l (cm)	$l < d$	$l \geq d$	ξ	P.E.	C.S.
Exp. 1	50.0	0.234	29.0	○		0.208	○	
Exp. 2	50.0	0.906	1.97	○		0.716		○
	48.03	0.996	0.0802	○		0.600		○
	47.95	0.183	34.0	○		0.868		○
	13.95	0.351	20.9		○			
		$l = (-\ln \xi) \times 20cm$						



Comparison of Monte Carlo Codes

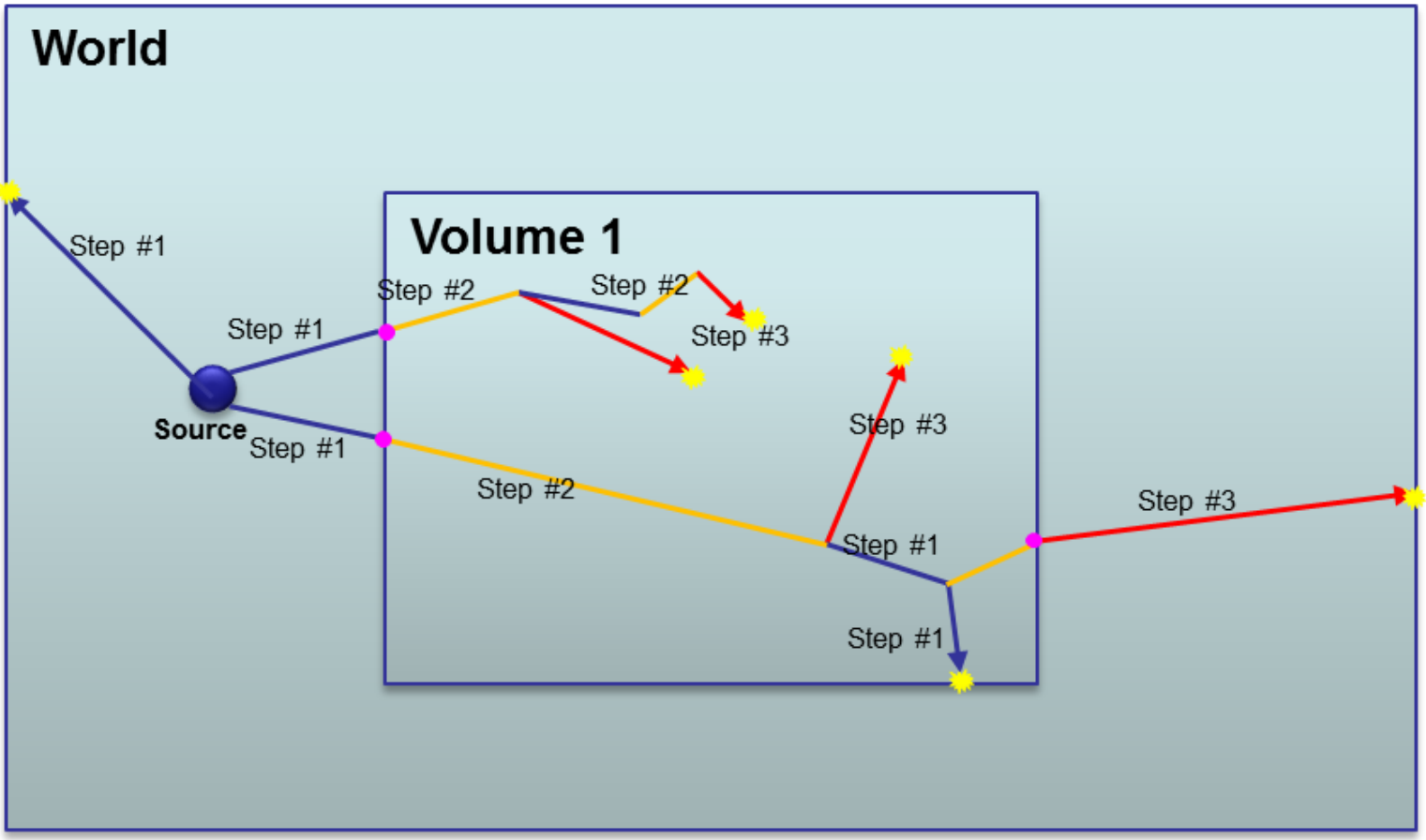
	MCNP	GEANT4	EGSnrc/EGS5	FLUKA
Language	Fortran	C++	Mortran/Fortran	Fortran
Particles	36 + all heavy ions	68 (unlimited)	3	65
Input	Macro	Coding	Coding/GUI	Macro/GUI
Input Cards	~120	N/A	N/A	~85
Parallel Execution	Yes	Yes	Yes	Yes
Cost	Varying	Free	Free	Free
Major user group	Nuclear engineering	High energy physics	Medical physics	High energy physics
Comments	Highly accurate for neutrons; criticality calculation possible	Flexile, E/B field, 4D simulation; **GATE**, TOPAS, PTSim	Well validated for photon and electrons; many user codes; BEAMnrc	Very high energy particles (10,000TeV); FLAIR
Website	http://mcnp.lanl.gov/	http://geant4.cern.ch/	http://www.irs.inms.nrc.ca/EGSnrc/EGSnrc.html	http://www.fluka.org/fluka.php

What is Geant4?

- Geant4(Geometry And Tracking)는 입자가 물질을 통과할 때 발생하는 물리적 상호작용을 전산모사하는 코드임.
- 80년대 개발된 fortran 언어 기반의 geant3는 고에너지 물리 실험에 사용되는 검출기 전산모사의 목적으로 만들어진 코드로써 geant4의 전신이 되었음.
- Geant4는 1994년 시작된 개발 프로젝트를 통해 객체지향 프로그래밍 언어인 C++을 기반으로 완전히 새롭게 재탄생 된 범용의 몬테칼로 코드임.
- C++ 기반의 오픈소스 툴킷으로 사용자가 직접 코딩해야 하는 어려움이 있으나, 다른 범용 몬테칼로 코드에 비하여 자유도가 매우 높음.
- 다양한 사용자 인터페이스, 가시화 툴, 히스토그래밍 툴과 연동되며, 4D 몬테칼로 전산모사가 가능함.
- 넓은 에너지 범위에서 다양한 물리모델의 선택사용이 가능하지만 선택에 따른 결과의 책임은 사용자에게 있다는 특징이 있음.

Kernel – Step and step point

- Step과 Step point

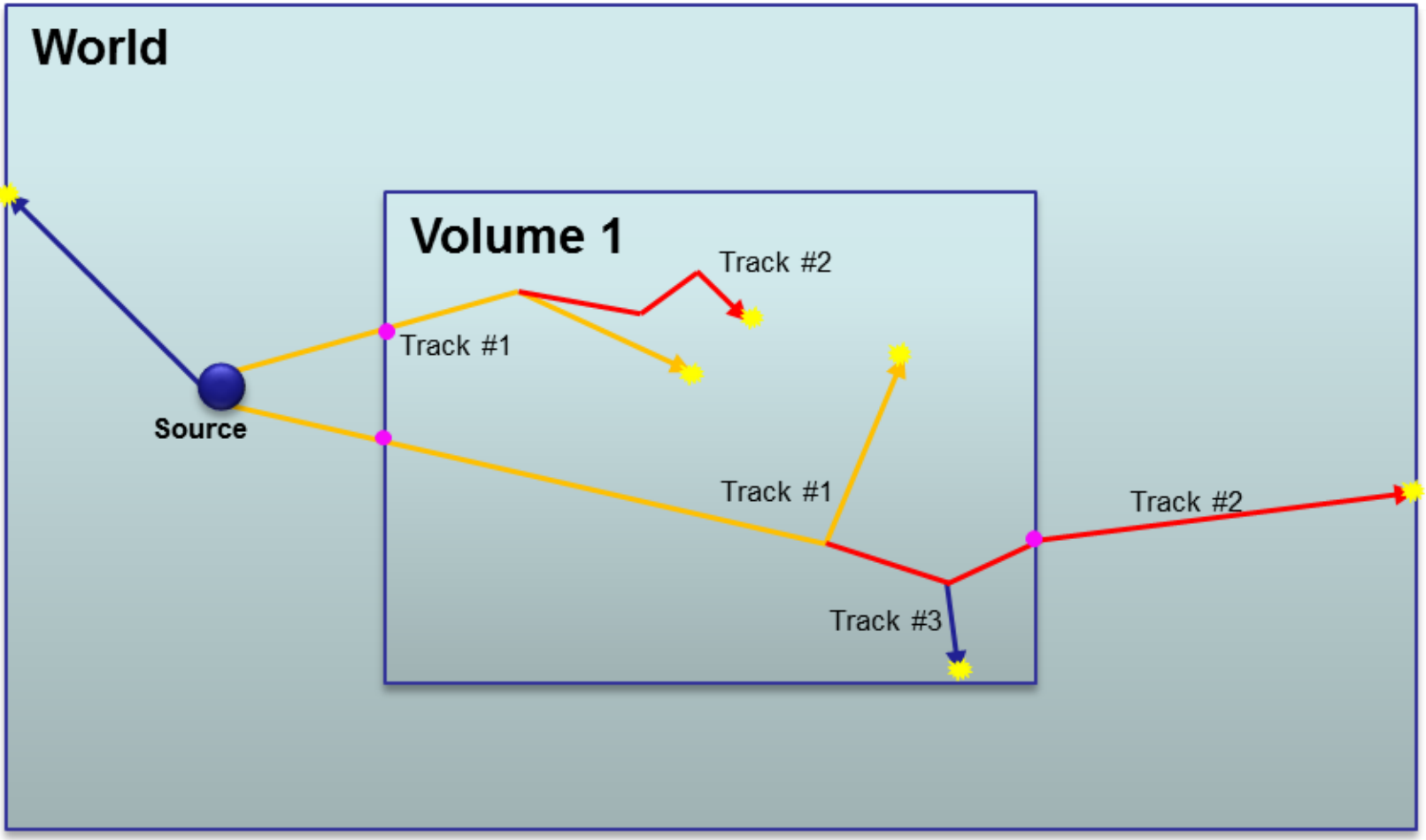


Kernel – Step and step point

- Step은 입자가 두 지점(pre-step point와 post-step point)을 이동하며 발생하는 변화 정보를 의미
- 여기서 변화정보는 에너지 손실이나 time-of-flight 등을 의미
- Step 을 정의하는 지점은 “반응 지점” 혹은 “매질의 경계지점“
- 매질의 경계 지점에서 분절된 경우 post-step point는 매질의 경계면 바로 다음에 위치하게 됨
- G4UserSteppingAction은 모든 step별로 특정 데이터를 처리하거나 저장하는데 사용됨.

Kernel – Track

- Track



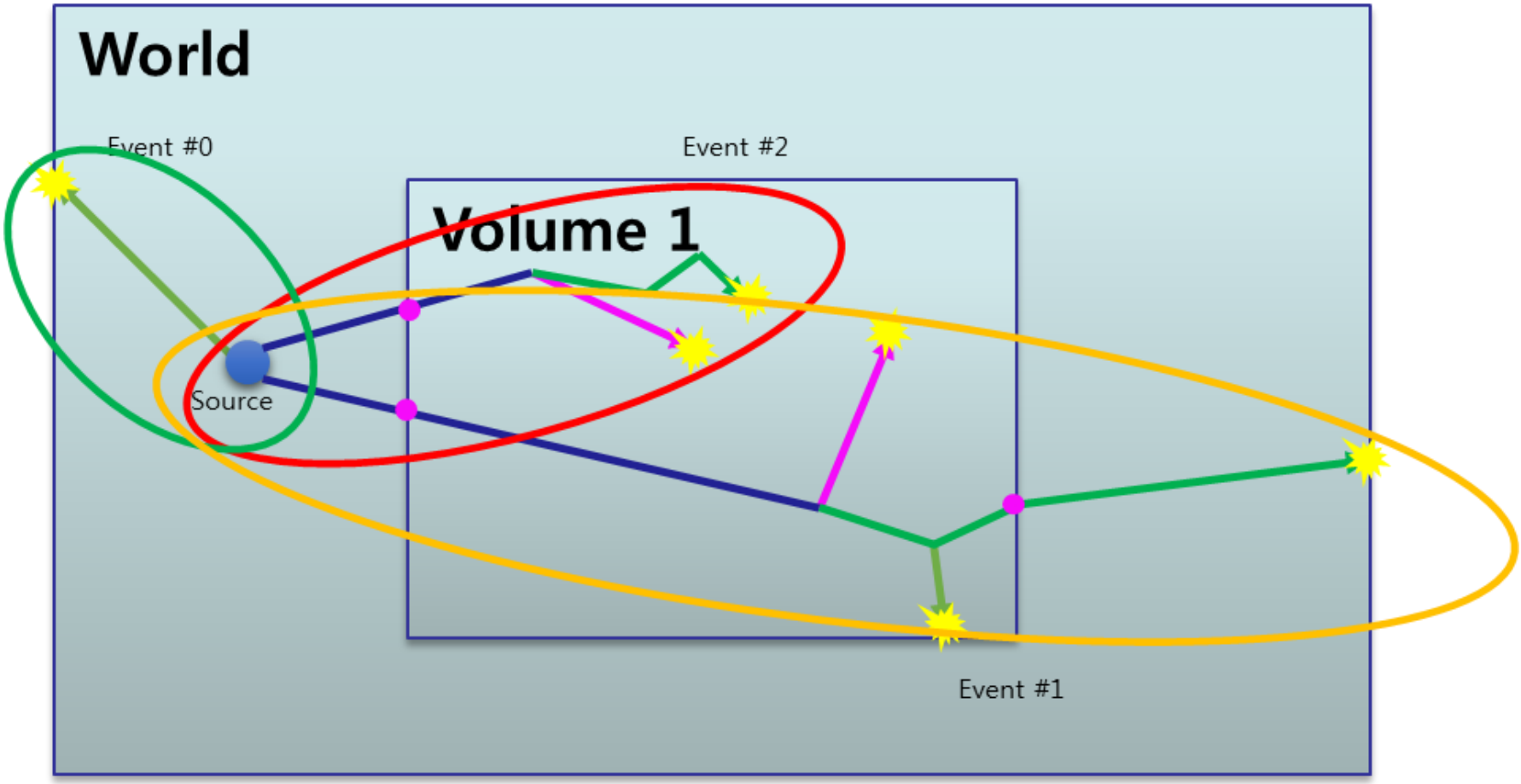
Kernel – Track

- Track은 입자의 스냅샷 정보를 의미
- Track은 step의 모음이 아니고 step으로 업데이트 되는 입자 정보임
- Tracking이 끝나고 track이 삭제되는 시점
  - World volum을 빠져나갔을 때
  - Decay나 inelastic scatterin으로 입자가 사라질 때
  - Kinetic energy가 0이 되었을 때
  - 사용자가 임의로 track을 kill 했을때
- G4UserTrackingAction Class에서 track의 정보를 획득 할 수 있음

- World volume 이란?
- 무한한 공간에서 시뮬레이션이 이뤄지는 경우 불필요한 계산시간이 소모되므로, 입자수송이 이뤄지는 공간을 한정하기 위해 정의되는 지오메트리.

Kernel – Event

- Event

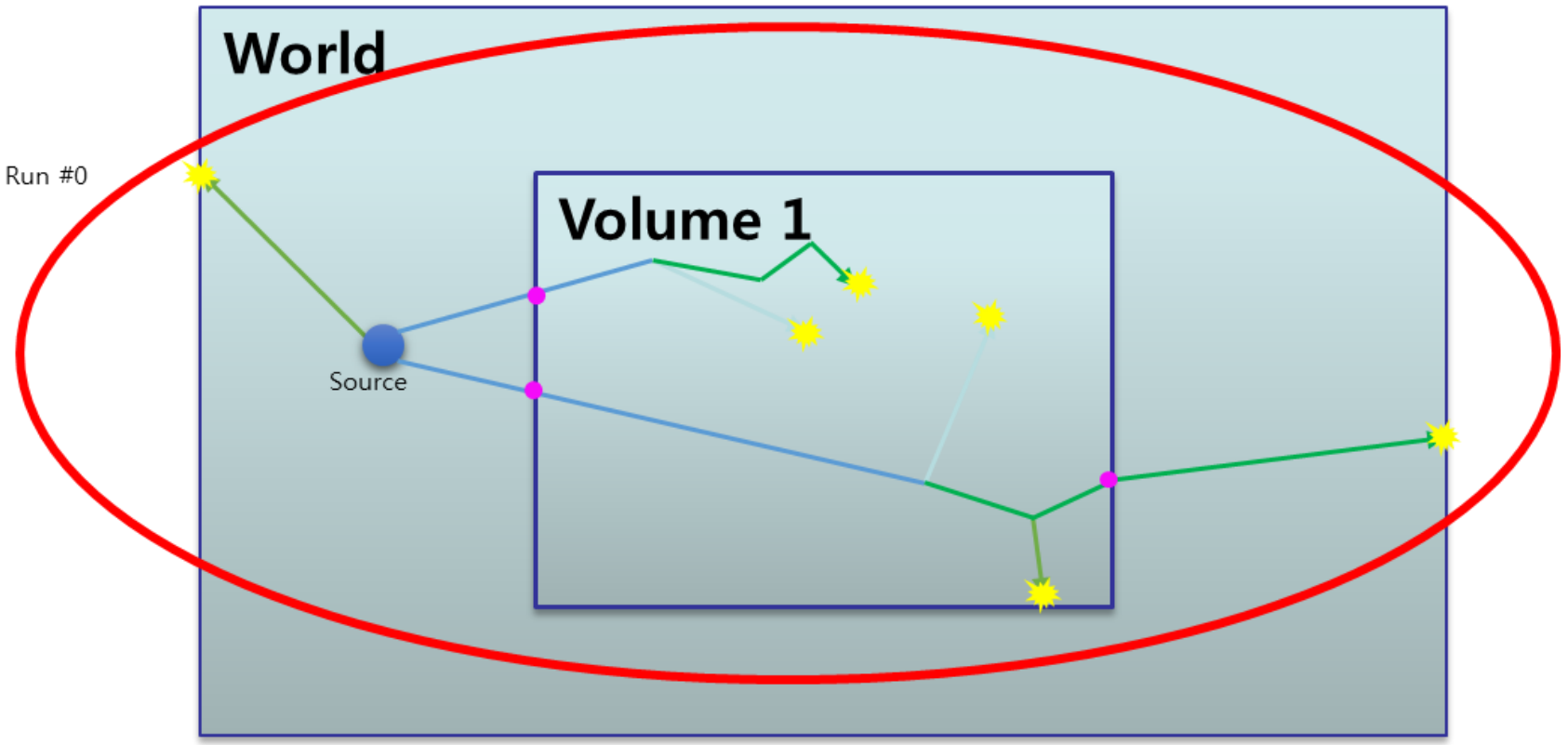


Kernel – Event

- 초기 입자가 생성되어 입자수송이 끝날 때 까지를 의미 (이차방사선의 입자수송 포함)
- 이차방사선 track은 초기 입자의 track 수송이 끝날 때 까지 스택에 쌓아 둠
- 초기 입자의 track 수송이 끝나면 제일 마지막에 생성된 이차 방사선 track부터 역순으로 수송 됨
- Stack이 비워지면 event가 종료됨
- G4UserEventAction 클래스를 사용하면 Event 단위 데이터를 처리 할 수 있음.

Kernel – Run

- Run



Kernel – Run

- “Beam On” 이라는 명령 또는 함수와 함께 사용되어 결정된 개수만큼의 초기입자에 대한 시뮬레이션을 수행한 전체 실행을 의미
- Run은 전체 event의 모음
- Run 실행 전 초기화 (Initialization) 단계에서 지오메트리가 입자수송을 위해 최적화되며, 물리모델을 바탕으로 사용된 매질에 따른 단위면적당 반응확률 (cross section) 테이블이 계산되기 때문에, run 실행 동안은 기본적으로 지오메트리와 물리모델의 변경이 불가함
- (*) Run동안 이벤트 단위로 변경 가능한 특수 지오메트리가 있음.

What is the GATE ?

❖**GATE**

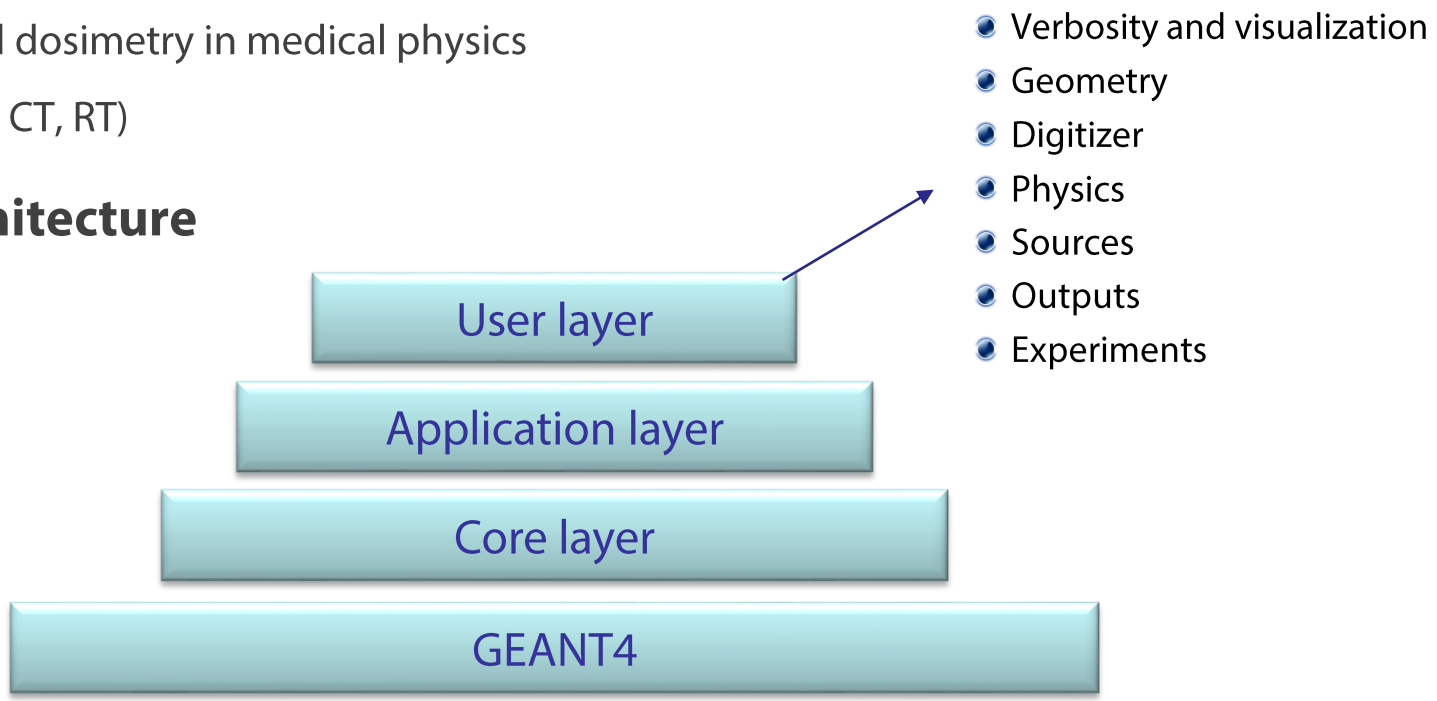
(Geant4 Application for Tomographic Emission)

❖**Widely used for**

- imaging and dosimetry in medical physics

(PET, SPECT, CT, RT)

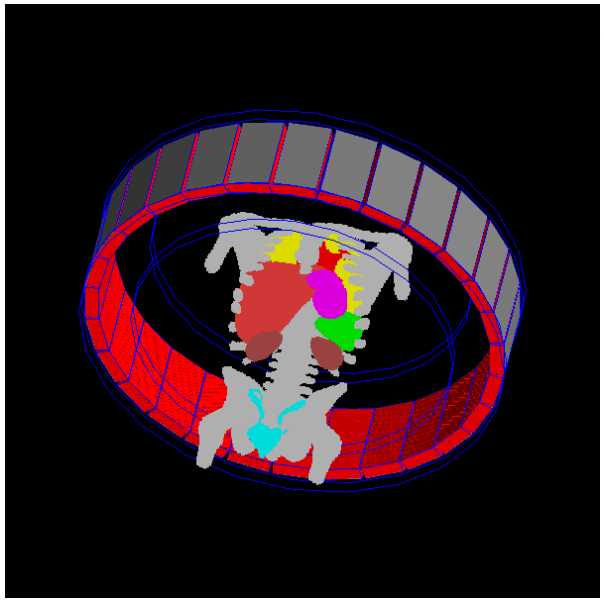
❖**GATE architecture**



Jan et al, PMB 49 (2004) 4543

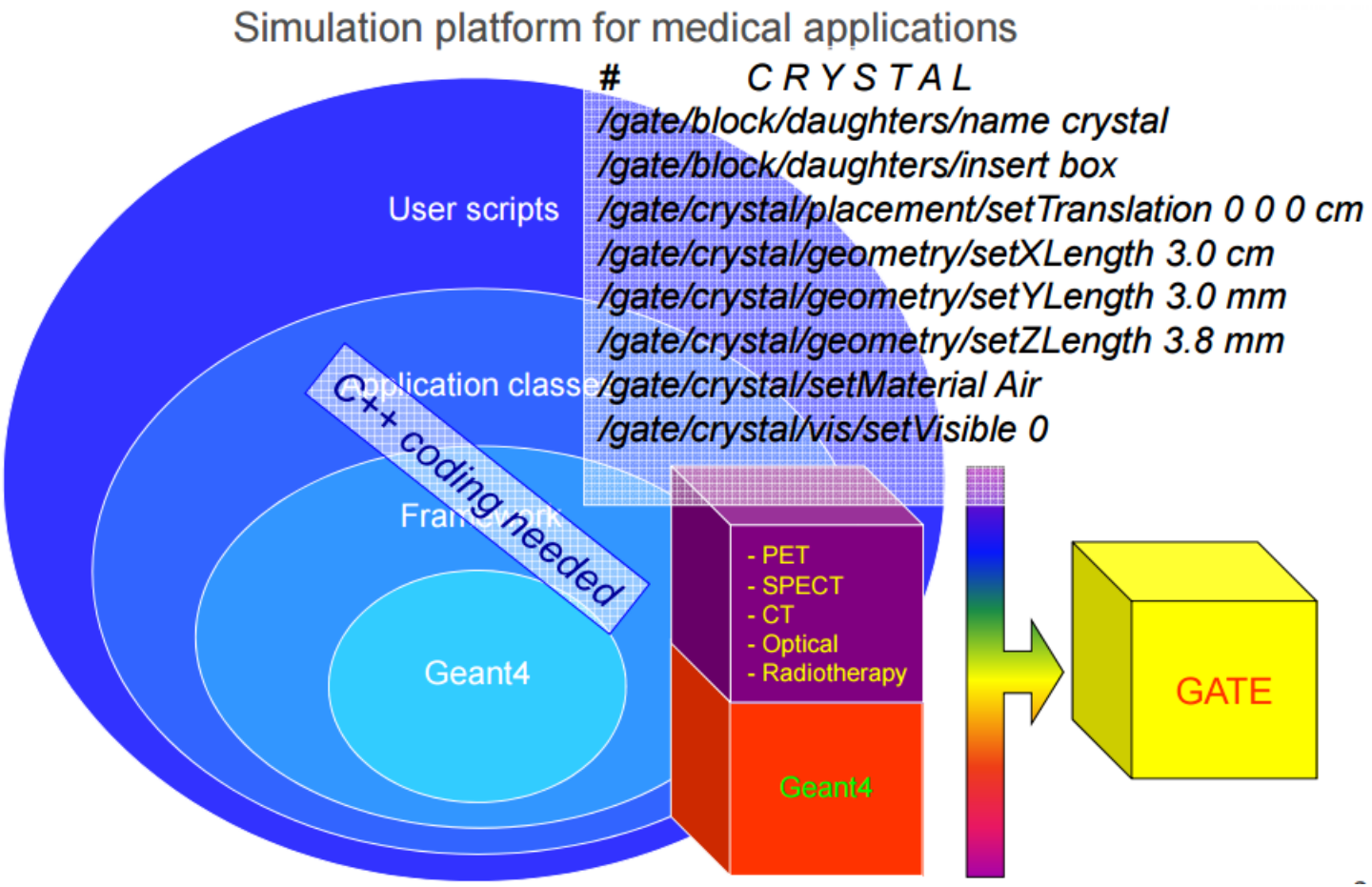
GATE time and movement

- Needed for
  - Patient and organ motion
  - Scanner rotation
  - Activity distribution changes
- Geant4 limitations
  - Geometry : static during simulation
  - No source movements



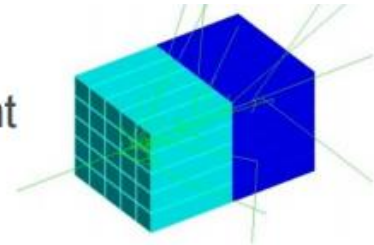
- Solutions in GATE
  - Geometry updated between simulation time steps
  - The source is confined to a smaller volume moving inside a larger emission volume

GATE structure



Detector & system description

- Standard Geant4 volumes
- Movement & Time Management
- Using every materials

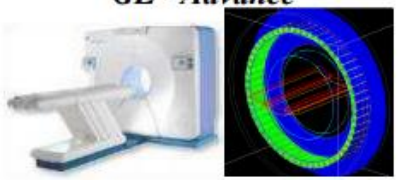


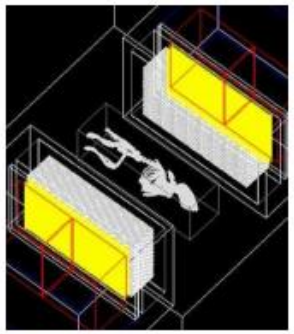
From simple volumes
TO
a complete device…

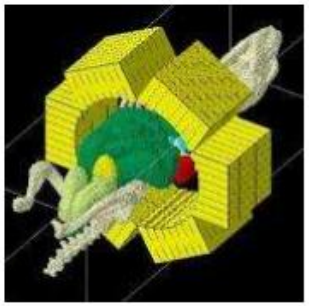
Siemens - ECAT EXACT HR+

Philips - Allegro

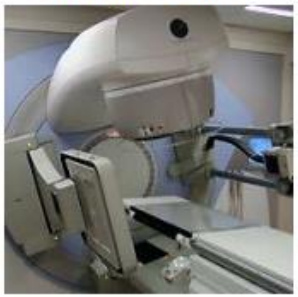
GE - Advance

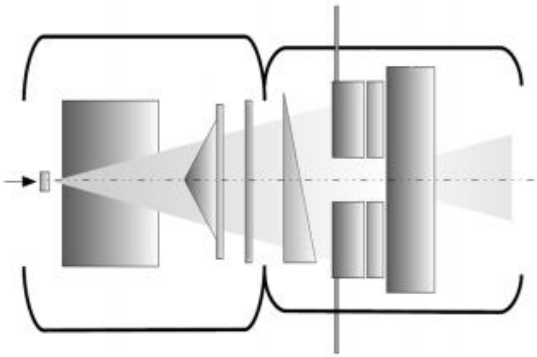




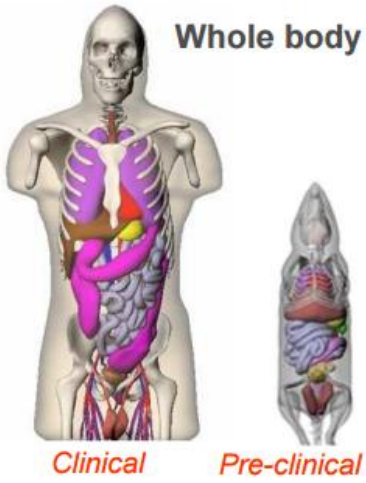


Elekta - Precise

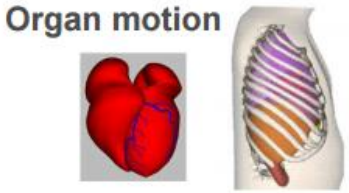




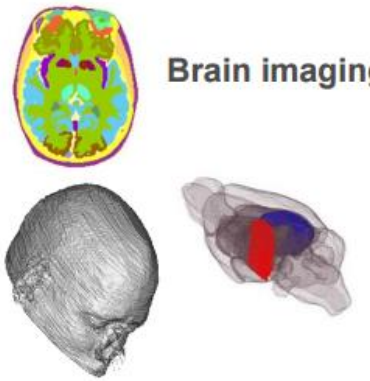
Geometry & Phantom description

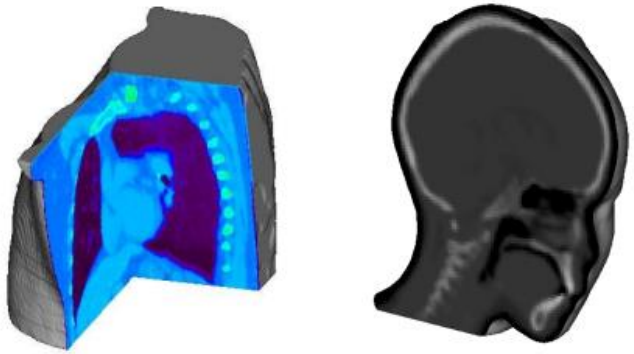


- Morphologic description
- Voxelized or analytical approach
- Realistic material database
- Organ motion description

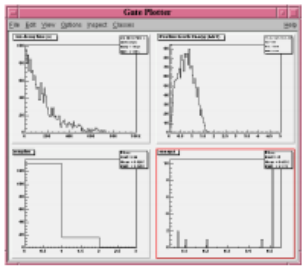


Radiation Therapy:
- CT patient images
- GATE converts HU values to the Geant4 material composition





Data output management

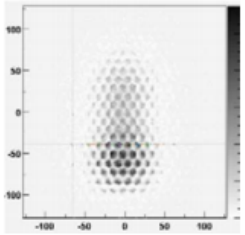


List mode oriented

- ROOT (most general output) ; ASCII
- LMF (cylindricalPET system)

Imaging applications

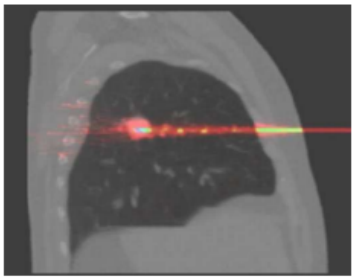
- Interfile projection (Optical or SPECT system)
- ECAT 7 (PET system)
- RAW sinogram (PET system)
- RAW projection (CT system)
- *easy to add a dedicated output…*



Radiotherapy and dosimetry applications

"Actors" + Filters based on G4 scorers and G4Filters

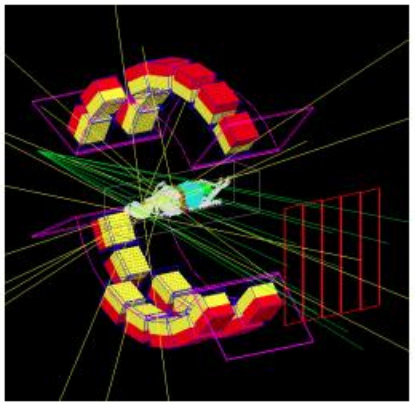
- *3D dose scorer (dose map – Analyze format)*
- *Simulation statistic*
- *Track killer*
- *…..*



Molecular and pre-clinical imaging

4D MOBY phantom

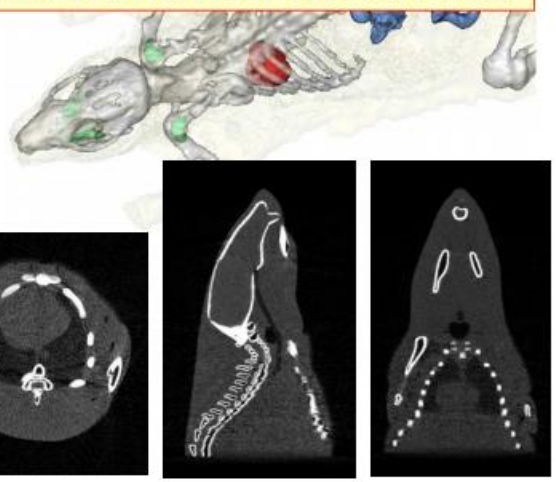
GATE simulation



Simulation result

CT scan simulation

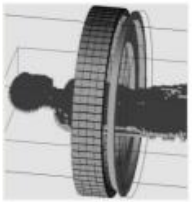
- PIXSCAN-XPAD3 developed in CPPM, Marseille
- X ray beam 17 keV
- Coupled with prototype PET scan
- Cluster of 10 CPUs & CPU time : 24h

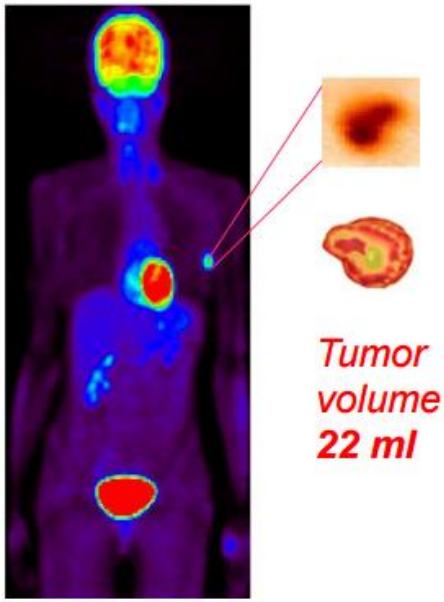


Oncology: Simulation of whole body scan

GATE Simulation

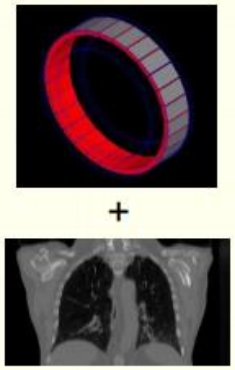
- Start acqui. : 264 MBq
- 7 bed positions
- 7' per bed position



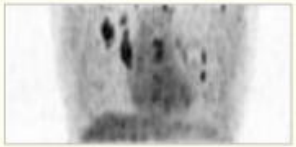


Tumor volume ***22 ml***

Simulation set-up



Simulation result



Since 2009: new navigator
Speed-up factor of 10 to 20

II. We make MYCT-EXAMPLE : Structure of CT example

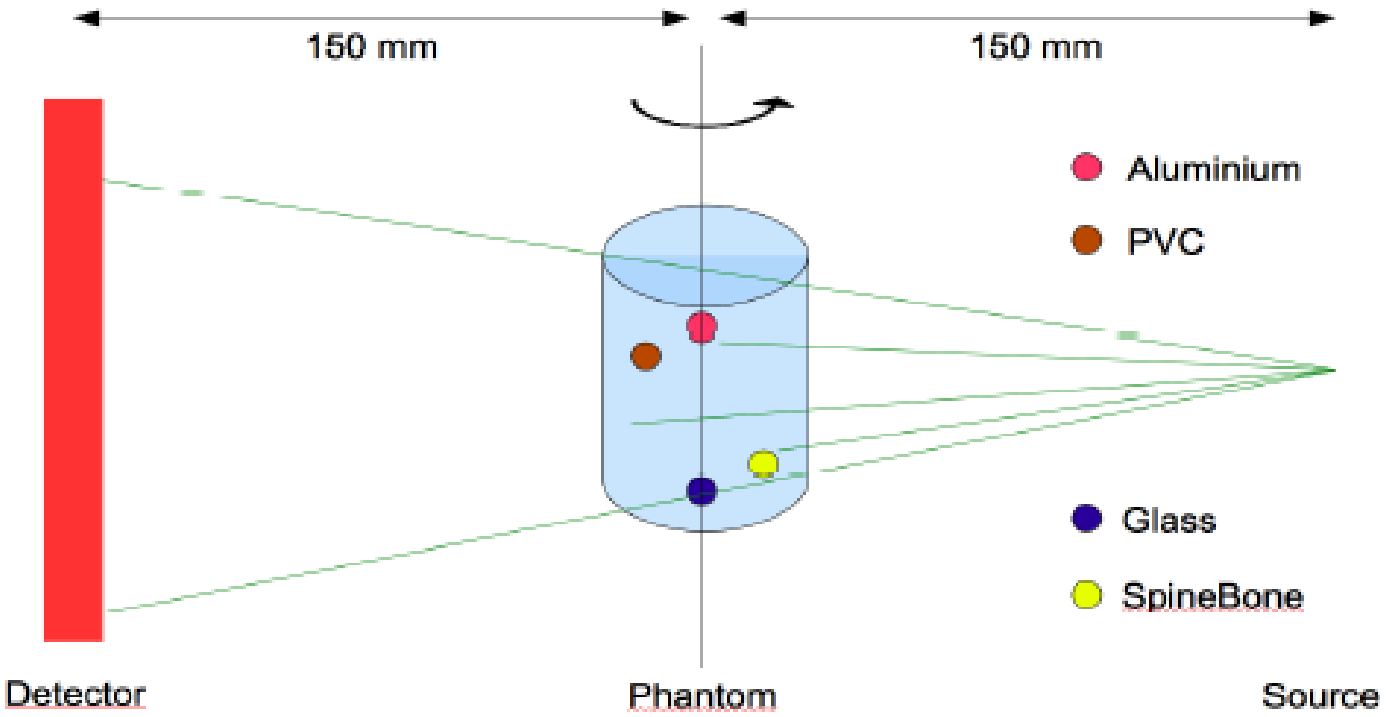
Archive → https://github.com/wjcheon/education_CTexample_wjcheon_Gate

CTexample (GATE)

- CT simulation
- The CT example simulation (built-in example)

Parts	Detail specification
Detector (CT scanner)	100 x 100 x 1 pixel: 0.5x0.5x1 mm^3 Material: Silicon
Phantom	1 cylinder Material: Water 4 balls Materials: Aluminium, Glass, SpineBone, PVC
Source	Type of particle: X-ray (6.8 degree angle emission)

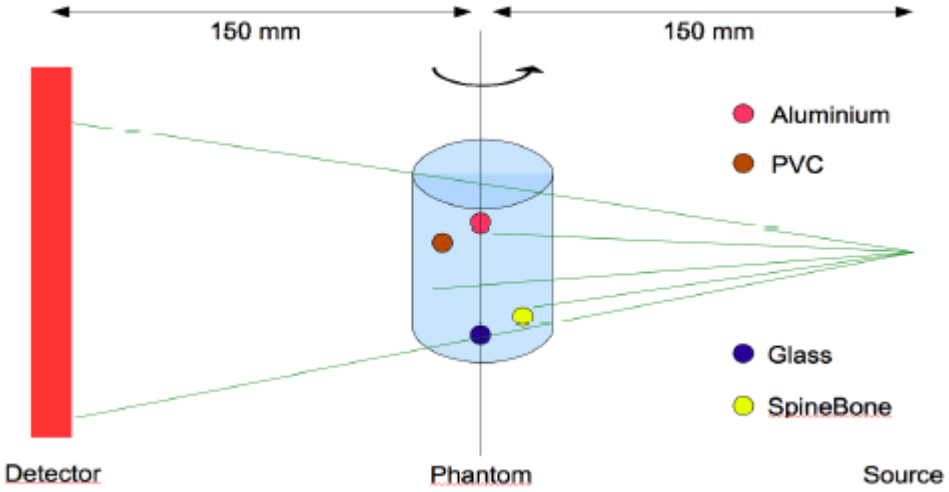
CTexample (GATE)



(1) MATERIALS

Materials

Geometry	Material
WORLD	AIR
CT Scanner (Detector)	Silicon
Phantom Cylinder	Water
Phantom balls	Aluminium
	Glasss
	SpineBone
	PVC



Materials

- Material Database predefined by OpenGate Collaboration group.
  - GateMaterial.db
  - patient-HUmaterials.db

- @Terminal
  - $ Gate --qt
- @QT
  - Session: /control/execute run.mac
- @Terminal
- GateMaterialDatabase.cc (l. 131): GateMaterialDatabase:
  could not find the definition for material 'Air' in material files.

GateMaterial.db :Element

- [Elements]
  - Hydrogen: S= H ; Z= 1. ; A= 1.01 g/mole
  - Helium: S= He ; Z= 2. ; A= 4.003 g/mole
  - Lithium: S= Li ; Z= 3. ; A= 6.941 g/mole
  - Beryllium: S= Be ; Z= 4. ; A= 9.012 g/mole
  - Boron: S= B ; Z= 5. ; A= 10.811 g/mole
  - Carbon: S= C ; Z= 6. ; A= 12.01 g/mole
  - Carbon_nrich: S= C ; Z= 6. ; A= 14.01 g/mole

    .

    .
  - Copper: S= Cu ; Z= 29. ; A= 63.39 g/mole

    .

    .

    .

GateMaterial.db :Material

- [Material]
- Air: d=1.29 mg/cm3 ; n=4 ; state=gas
  - +el: name=Nitrogen ; f=0.755268
  - +el: name=Oxygen ; f=0.231781
  - +el: name=Argon ; f=0.012827
  - +el: name=Carbon ; f=0.000124
- Water: d=1.00 g/cm3; n=2 ; state=liquid
  - +el: name=Hydrogen ; n=2
  - +el: name=Oxygen ; n=1
- SpineBone: d=1.42 g/cm3 ; n=11
  - +el: name=Hydrogen ; f=0.063
  - +el: name=Carbon ; f=0.261
  - +el: name=Nitrogen ; f=0.039
  - +el: name=Oxygen ; f=0.436
  - +el: name=Sodium ; f=0.001
  - +el: name=Magnesium ; f=0.001
  - +el: name=Phosphor ; f=0.061
  - +el: name=Sulfur ; f=0.003
  - +el: name=Chlorine ; f=0.001
  - +el: name=Potassium ; f=0.001
  - +el: name=Calcium ; f=0.133

Geometry	Material
WORLD	AIR
CT Scanner (Detector)	Silicon
Phantom Cylinder	Water
Phantom balls	Aluminium
	Glasss
	SpineBone
	PVC

GateMaterial.db :Element as material

- [Element as materials]
- Vacuum: d=0.000001 mg/cm3 ; n=1

  +el: name=Hydrogen ; n=1
- Aluminum: d=1.350 g/cm3 ; n=1 ; state=solid

  +el: name=auto ; n=1
- Uranium: d=18.90 g/cm3 ; n=1 ; state=solid

  +el: name=auto ; n=1
- Copper: d=8.96 g/cm3 ; n=1

  +el: name=Copper ; f=1.0

GateMaterial.db :Mixtures as materials

- [Mixtures as materials]
- Lung: d=0.26 g/cm3 ; n=9
  +el: name=Hydrogen ; f=0.103
  +el: name=Carbon ; f=0.105
  +el: name=Nitrogen ; f=0.031
  +el: name=Oxygen ; f=0.749
  +el: name=Sodium ; f=0.002
  +el: name=Phosphor ; f=0.002
  +el: name=Sulfur ; f=0.003
  +el: name=Chlorine ; f=0.003
  +el: name=Potassium ; f=0.002

- SS304: d=7.92 g/cm3 ; n=4 ; state=solid
  +el: name=Iron ; f=0.695
  +el: name=Chromium ; f=0.190
  +el: name=Nickel ; f=0.095
  +el: name=Manganese ; f=0.020

GateMaterial.db
:Mixture of mixtures as materials

- [Mixtures of mixtures as materials]
- Aerogel: d=0.200 g/cm3 ; n=3

  +mat: name=SiO2 ; f=0.625

  +mat: name=Water ; f=0.374

  +el: name=Carbon ; f=0.001

Material of patient (example)
Patient-HU2materials.db

- Air_0
- Lung_1~9
- AT_AG_SI1_10~14
- AT_AG_SI2_11
- AT_AG_SI3_12
- AT_AG_SI4_13
- AT_AG_SI5_14
- SoftTissus_15
- ConnectiveTissue_16
- Marrow_Bone01_17~31
- AmalgamTooth_32~25
- MetalIImplants_36~41

VIP-Man phantom developed by RRMDG at Rensselaer Polytechnic Institute in Troy, NY.[11]

Patient-HU2materials.db :Mixtures as materials

- # Material corresponding to H=[-658;-561]
- Lung_4: d=402.695 mg/cm3; n=9;
  - +el: name=Hydrogen; f=0.103
  - +el: name=Carbon; f=0.105
  - +el: name=Nitrogen; f=0.031
  - +el: name=Oxygen; f=0.749
  - +el: name=Sodium; f=0.002
  - +el: name=Phosphor; f=0.002
  - +el: name=Sulfur; f=0.003
  - +el: name=Chlorine; f=0.003
  - +el: name=Potassium; f=0.002

- # Material corresponding to H=[1400;1500]
- Marrow_Bone14_30: d=1.87534 g/cm3 ; n=9;
  - +el: name=Hydrogen; f=0.036
  - +el: name=Carbon; f=0.165
  - +el: name=Nitrogen; f=0.042
  - +el: name=Oxygen; f=0.432
  - +el: name=Sodium; f=0.001
  - +el: name=Magnesium; f=0.002
  - +el: name=Phosphor; f=0.1
  - +el: name=Sulfur; f=0.003
  - +el: name=Calcium; f=0.219

- # Material corresponding to H=[1500;1640]
- Marrow_Bone15_31: d=1.94643 g/cm3 ; n=9;
  - +el: name=Hydrogen; f=0.034
  - +el: name=Carbon; f=0.155
  - +el: name=Nitrogen; f=0.042
  - +el: name=Oxygen; f=0.435
  - +el: name=Sodium; f=0.001
  - +el: name=Magnesium; f=0.002
  - +el: name=Phosphor; f=0.103
  - +el: name=Sulfur; f=0.003
  - +el: name=Calcium; f=0.225

Process of voxel value to material

Step1
- Read the value of voxel.

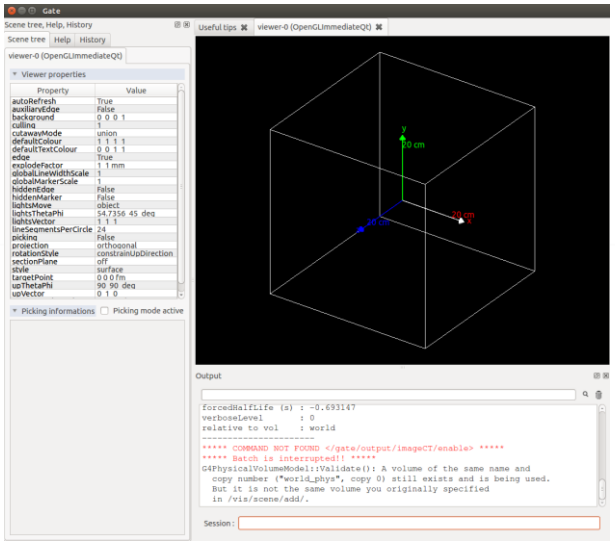
Step2
- Find the Material that corresponds to the value

Step3
- The material is assigned to the voxel.

Patient-HU2mat.txt

- -1050 -950 Air_0
- -950 -852 Lung_1
- -852 -755 Lung_2
- -270 -173 Lung_8
- -173 -120 Lung_9
- -120 -82 AT_AG_SI1_10
- 500 600 Marrow_Bone05_21
- 600 700 Marrow_Bone06_22
- 700 800 Marrow_Bone07_23
- 800 900 Marrow_Bone08_24
- 900 1000 Marrow_Bone09_25
- 1975 2142 AmalgamTooth_34
- 2142 2300 AmalgamTooth_35
- 2970 3000 MetalIImplants_40
- 3000 3001 MetalIImplants_41

Materials

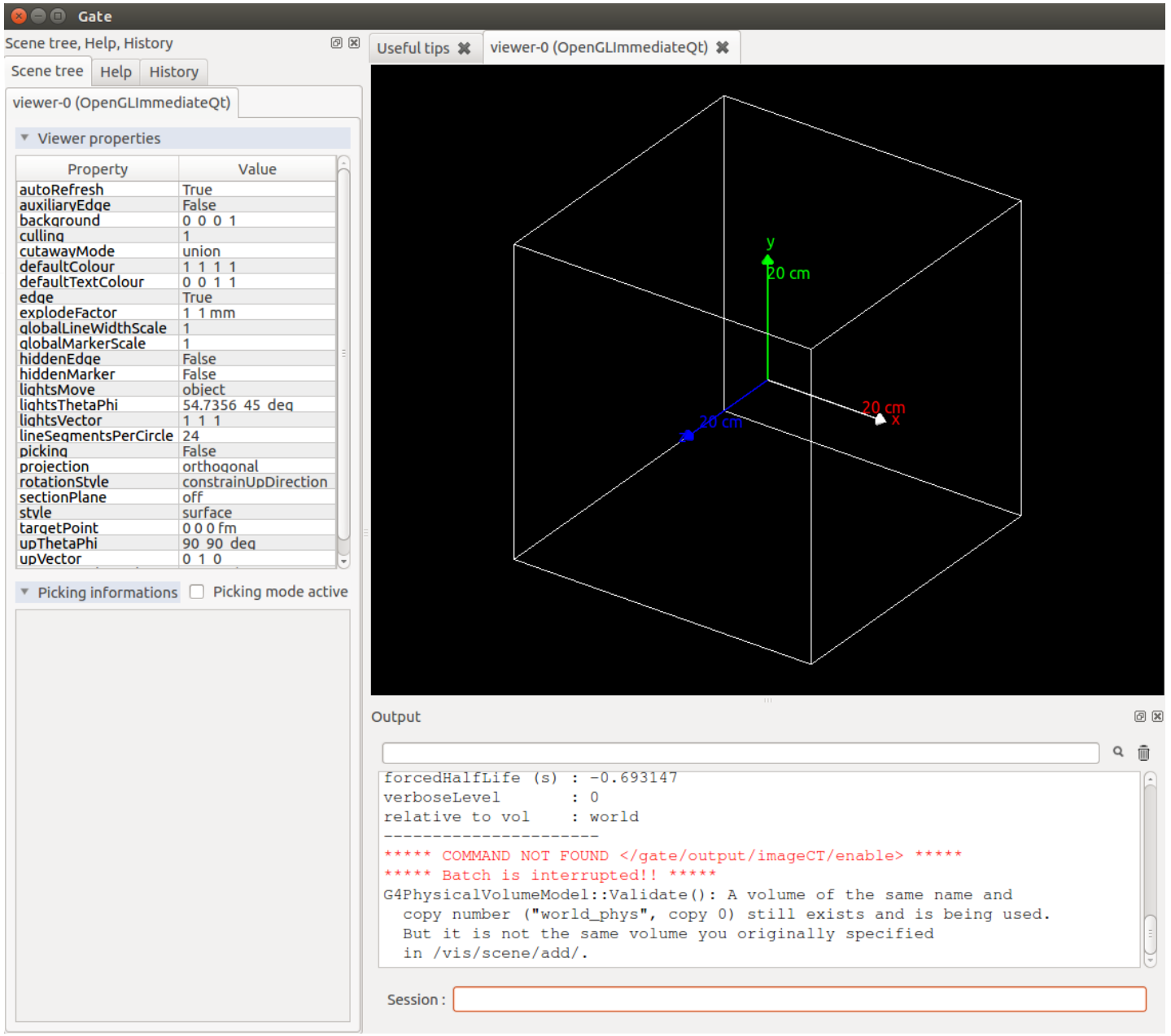


- Material Database predefined by OpenGate Collaboration group.
  - GateMaterial.db
  - patient-Humaterials.db

- @Terminal
  - $ Gate --qt
- @QT
  - Session: /control/execute run.mac
- @Terminal
  - GateMaterialDatabase.cc (l. 131): GateMaterialDatabase: could not find the definition for material 'Air' in material files.

- @run.mac
  - HandsOn #1
  - /gate/geometry/setMaterialDatabase ./MaterialDB/GateMaterials.db

- @Terminal
  - $ Gate –qt
- @Qt
  - Session: /control/execute run.mac



(2) GEOMETRY

World / Detector / Phantom

Kinds of volume @Genat4

Solid & Shape	• Shape of geometry
Logical_ volume	• Sol_volume + Material
Physical_ volume	• Logical_volume + location (Translation, Rotation, Position)

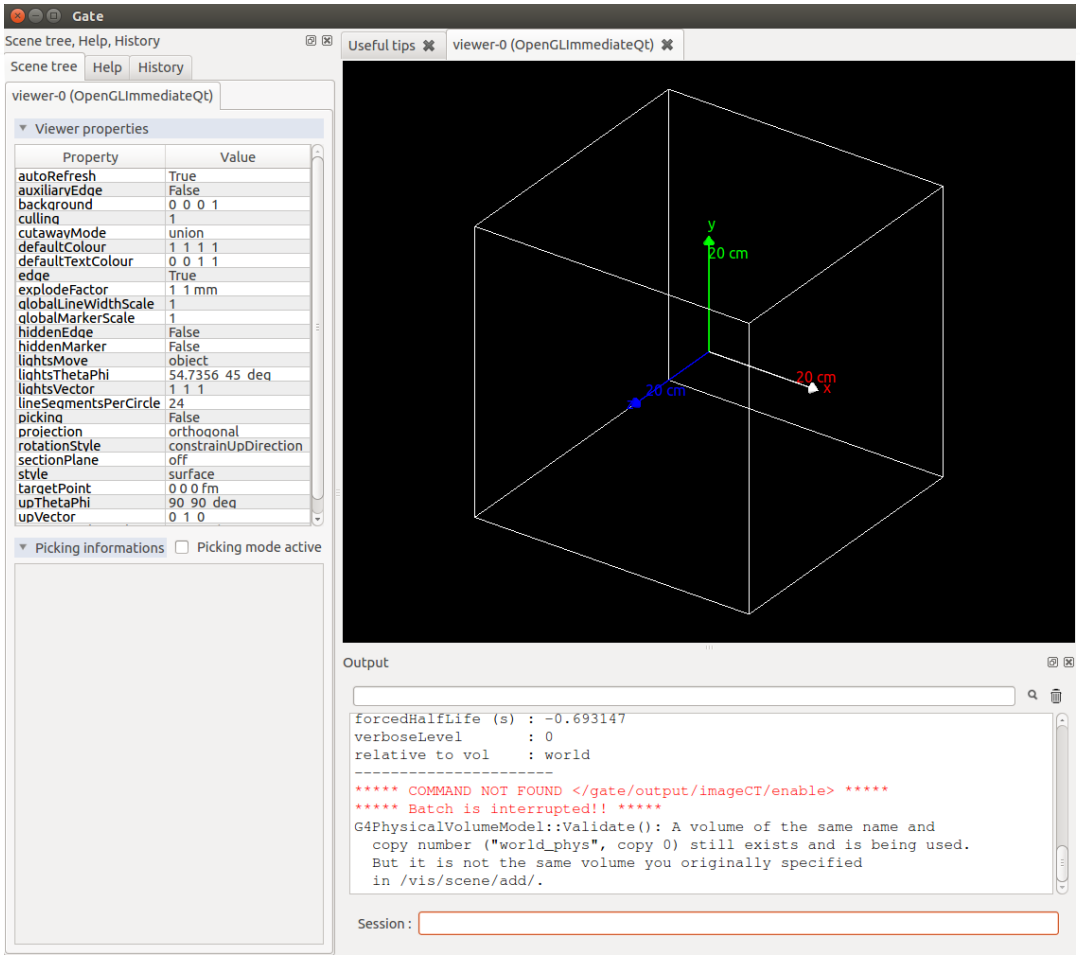
World

- The *world* is the only volume already defined in GATE when starting a macro.
- All volumes are defined as daughters or grand-daughters of the *world*.
- The *world* volume is a typical example of a GATE volume and has predefined properties.
- The *world* volume is a box centred at the origin.
- For any particle, tracking stops when it escapes from the *world* volume.
- The *world* volume can be of any size and has to be large enough to include all volumes involved in the simulation.

@run.mac

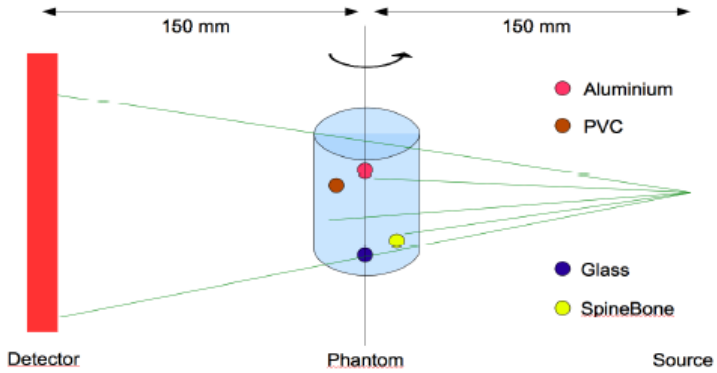
- #########
- # WORLD #
- #########
- /gate/world/geometry/setXLength 50. cm
- /gate/world/geometry/setYLength 50. cm
- /gate/world/geometry/setZLength 50. cm
- /gate/world/setMaterial Air

World



Detector (CT scanner)

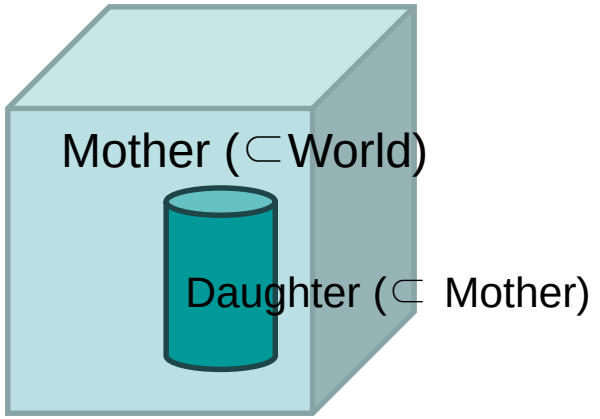
- **@run.mac**
- ##
- # CT scanner for small animal imaging #
- # 150x200 pixels #
- # size of pixels : 0.5x0.5x1.0 mm3 #
- # pixels are made up of silicon #
- ##
- # HandOn #2
- # Define detector geometry (CTscannerFast.mac)
- #/control/execute CTScannerFast.mac



CTScannerFast.mac

```
####################
# CTscanner system #
####################
/gate/world/daughters/name CTscanner
/gate/world/daughters/insert box
/gate/CTscanner/geometry/setXLength 50. mm
/gate/CTscanner/geometry/setYLength 50. mm
/gate/CTscanner/geometry/setZLength 1. mm
/gate/CTscanner/setMaterial Air
/gate/CTscanner/placement/setTranslation 0. 0. 150.5 mm
/gate/CTscanner/vis/forceWireframe
/gate/CTscanner/vis/setColor white

#############        ############
# CTSCANNER #  ---->  #  MODULE  #
#############        ############
/gate/CTscanner/daughters/name module
/gate/CTscanner/daughters/insert box
/gate/module/geometry/setXLength 50. mm
/gate/module/geometry/setYLength 50. mm
/gate/module/geometry/setZLength  1. mm
/gate/module/setMaterial Silicon
/gate/module/vis/forceWireframe
/gate/module/vis/setColor white

# ATTACH SYSTEM
/gate/systems/CTscanner/module/attach module

# ATTACH LAYER
/gate/module/attachCrystalSD
```

Volume (⊂ Coordinate system)



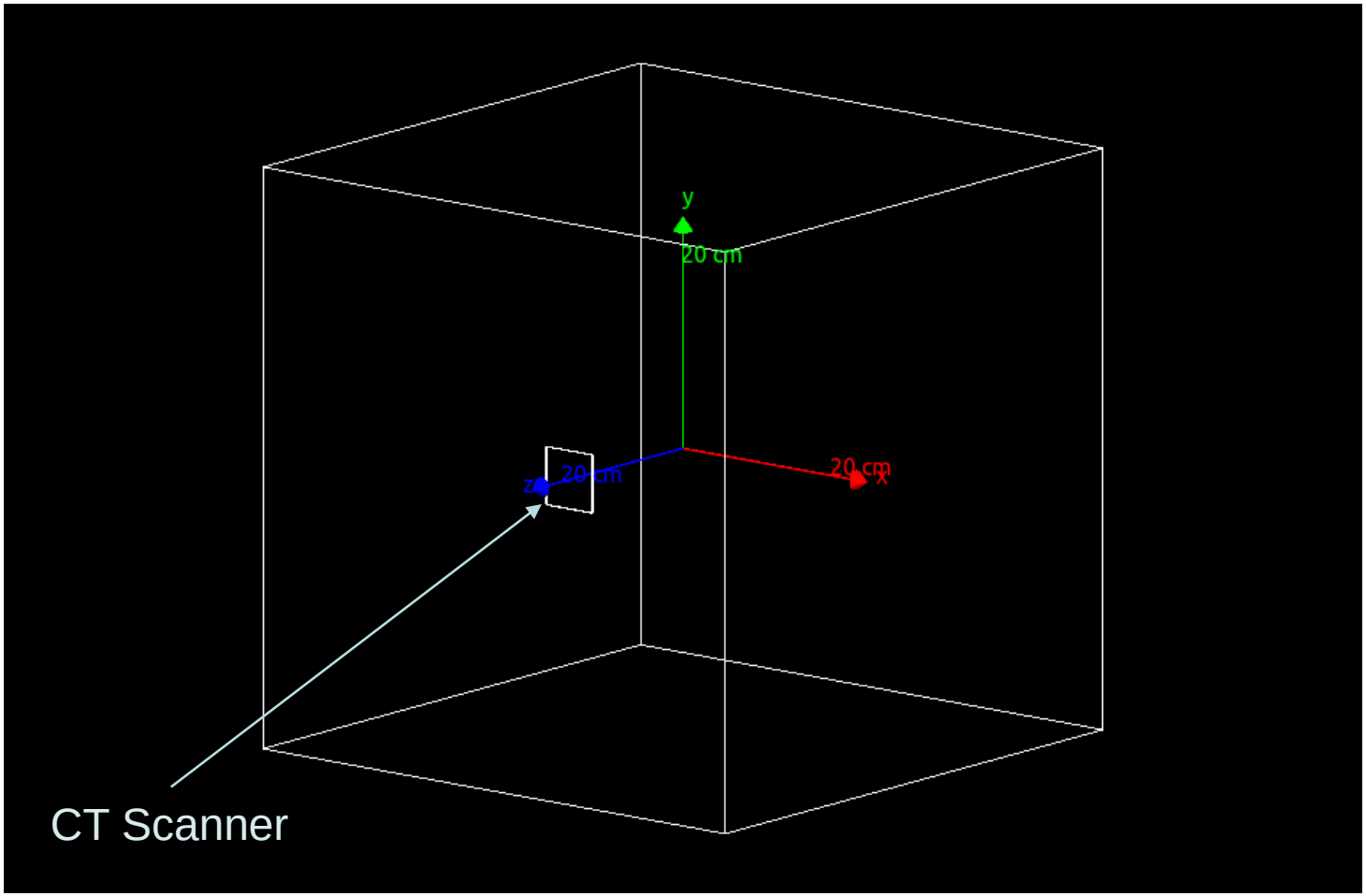

```
/gate/module/placement/setTranslation 0. 0. 0. mm (생략)
```

Detector (CT scanner)

- **@run.mac**
- ##
- # CT scanner for small animal imaging #
- # 150x200 pixels #
- # size of pixels : 0.5x0.5x1.0 mm3 #
- # pixels are made up of silicon #
- ##
- # HandOn #2
- # Define detector geometry (CTscannerFast.mac)
- /control/execute CTScannerFast.mac

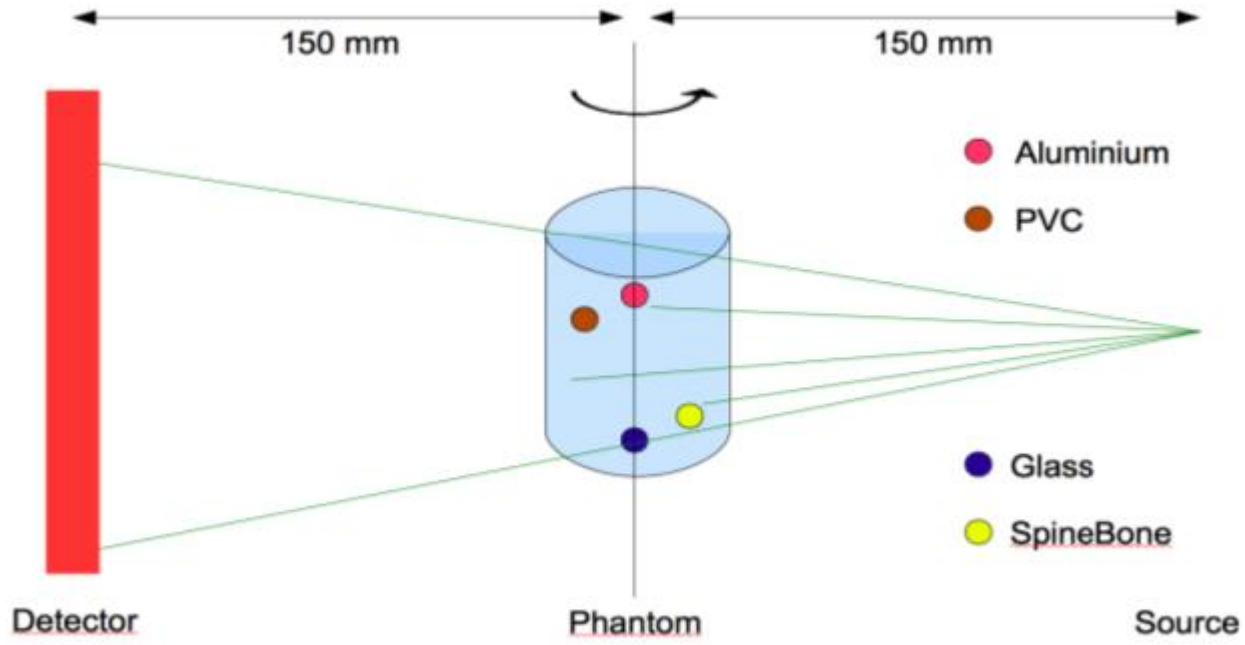
- @Terminal
  - $Gate --qt
- @ QT
  - Session: /control/execute run.mac

Detector (CT Scanner)



Phantom

- @ run.mac
- # HandOn #3
- # Define phantom geometry (CTscannerFast.mac)
- /control/execute phantom.mac



phantom.mac

- ##################
- # Water Cylinder #
- ##################
- /gate/world/daughters/name waterCylinder
- /gate/world/daughters/insert cylinder
- /gate/waterCylinder/geometry/setRmin 0. mm
- /gate/waterCylinder/geometry/setRmax 8. mm
- /gate/waterCylinder/geometry/setHeight 20. mm
- /gate/waterCylinder/setMaterial Water
- /gate/waterCylinder/placement/setRotationAxis 1 0 0
- /gate/waterCylinder/placement/setRotationAngle 90. deg
- /gate/waterCylinder/vis/forceWireframe
- /gate/waterCylinder/vis/setColor cyan

Ball#1 (Aluminium)

- ####################
- # Aluminium Balls #
- ####################
- /gate/waterCylinder/daughters/name aluminiumBall
- /gate/waterCylinder/daughters/insert sphere
- /gate/aluminiumBall/geometry/setRmin 0. mm
- /gate/aluminiumBall/geometry/setRmax 1. mm
- /gate/aluminiumBall/setMaterial Aluminium
- /gate/aluminiumBall/placement/setTranslation 4.76314 -2.75 -6. mm
- /gate/aluminiumBall/vis/setColor white

Ball#2 (PVC)

- /gate/waterCylinder/daughters/name PVCBall
- /gate/waterCylinder/daughters/insert sphere
- /gate/PVCBall/geometry/setRmin 0. mm
- /gate/PVCBall/geometry/setRmax 1. mm
- /gate/PVCBall/setMaterial PVC
- /gate/PVCBall/placement/setTranslation 4.76314 2.75 -6. mm
- /gate/PVCBall/vis/setColor cyan

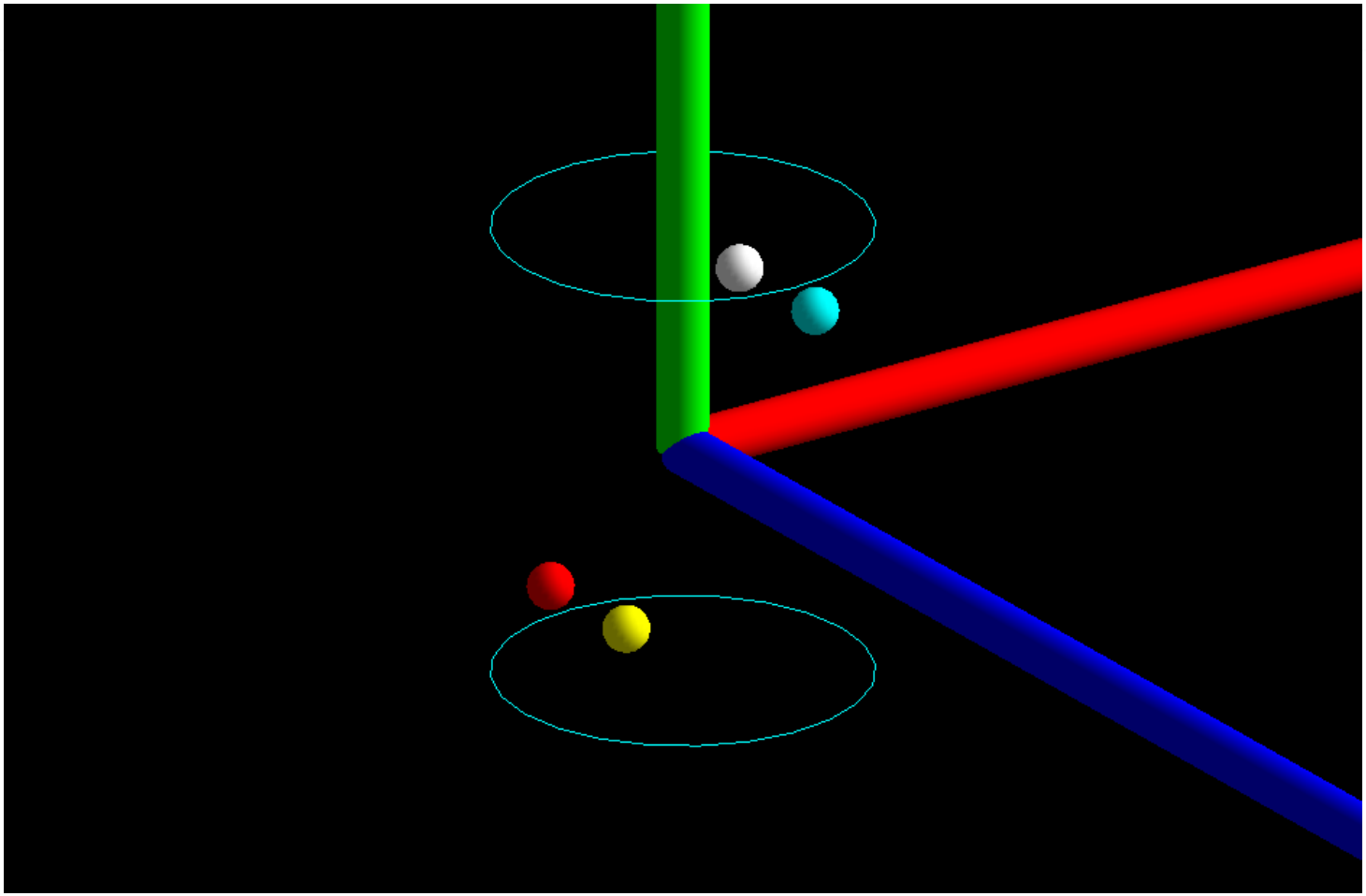
Ball#3 (Glass)

- /gate/waterCylinder/daughters/name glassBall
- /gate/waterCylinder/daughters/insert sphere
- /gate/glassBall/geometry/setRmin 0. mm
- /gate/glassBall/geometry/setRmax 1. mm
- /gate/glassBall/setMaterial Glass
- /gate/glassBall/placement/setTranslation -4.76314 -2.75 6. mm
- /gate/glassBall/vis/setColor red

Ball#4 (SpineBone)

- gate/waterCylinder/daughters/name spineBoneBall
- /gate/waterCylinder/daughters/insert sphere
- /gate/spineBoneBall/geometry/setRmin 0. mm
- /gate/spineBoneBall/geometry/setRmax 1. mm
- /gate/spineBoneBall/setMaterial SpineBone
- /gate/spineBoneBall/placement/setTranslation -4.76314 2.75 6. mm
- /gate/spineBoneBall/vis/setColor yellow

Phantom



Translation and Rotation of Geometry

- @CTscanner.mac
- ####################
- # CTscanner system #
- ####################
- /gate/world/daughters/name CTscanner
- /gate/world/daughters/insert box
- /gate/CTscanner/geometry/setXLength 50. mm
- /gate/CTscanner/geometry/setYLength 50. mm
- /gate/CTscanner/geometry/setZLength 1. mm
- /gate/CTscanner/setMaterial Air
- /gate/CTscanner/placement/setTranslation 0. 0. 150.5 mm
- /gate/CTscanner/vis/forceWireframe
- /gate/CTscanner/vis/setColor white

Translation

To translate the *Name_Volume* volume along the X direction by x cm, the command is:

```
/gate/Name_Volume/placement/setTranslation x. 0. 0. cm
```

The position is always given with respect to the center of the mother volume.

To set the Phi angle (in XY plane) of the translation vector, use:

```
/gate/Name_Volume/placement/setPhiOfTranslation N deg
```

To set the Theta angle (with regard to the Z axis) of the translation vector, use:

```
/gate/Name_Volume/placement/setThetaOfTranslation N deg
```

To set the magnitude of the translation vector, use:

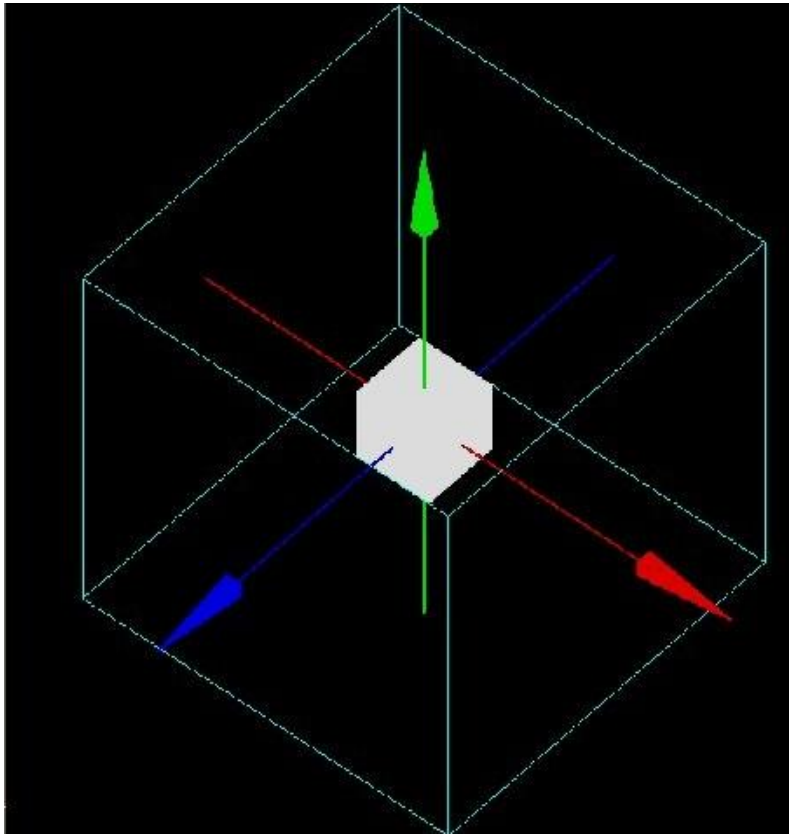
```
/gate/Name_Volume/placement/setMagOfTranslation xx cm
```

- Example

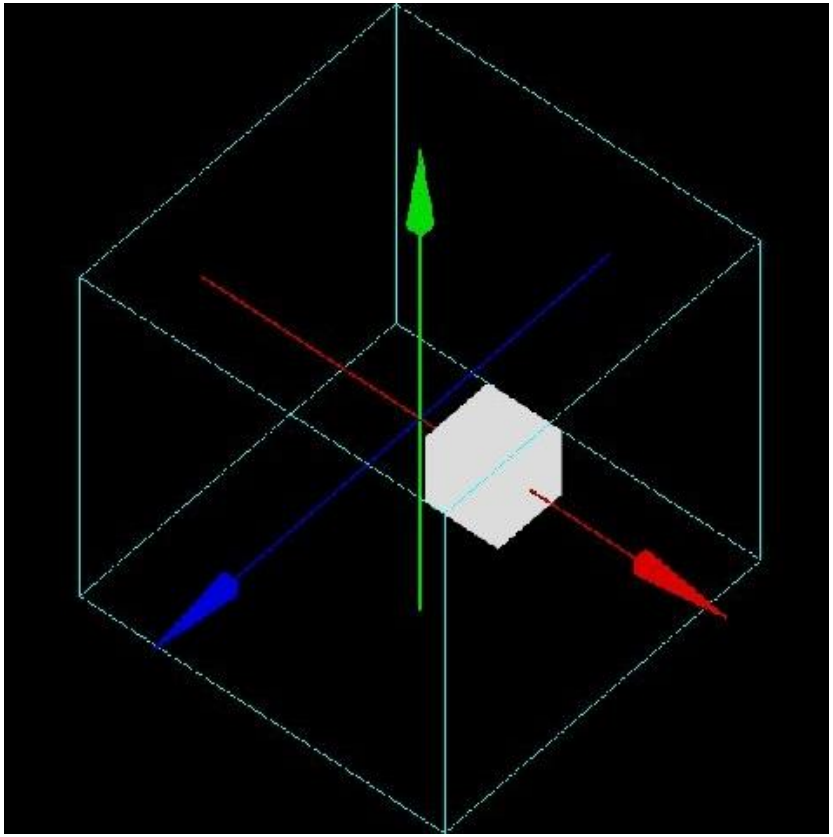
```
/gate/Phantom/placement/setTranslation 1. 0. 0. cm
/gate/Phantom/placement/setMagOfTranslation 10. cm
```

Translation and Rotation of Geometry

Original geometry



Translation



Translation and Rotation of Geometry

- @ phantom.mac
- ##################
- # Water Cylinder #
- ##################
- /gate/world/daughters/name waterCylinder
- /gate/world/daughters/insert cylinder
- /gate/waterCylinder/geometry/setRmin 0. mm
- /gate/waterCylinder/geometry/setRmax 8. mm
- /gate/waterCylinder/geometry/setHeight 20. mm
- /gate/waterCylinder/setMaterial Water
- /gate/waterCylinder/placement/setRotationAxis 1 0 0
- /gate/waterCylinder/placement/setRotationAngle 90. deg
- /gate/waterCylinder/vis/forceWireframe
- /gate/waterCylinder/vis/setColor cyan

- @ run.mac
- # HandOn #4
- # Define options for phantom geometry
- /gate/waterCylinder/moves/insert rotation
- /gate/waterCylinder/rotation/setSpeed 1. deg/s
- /gate/waterCylinder/rotation/setAxis 0 0 1

Rotation

To rotate the *Name_Volume* volume by *N* degrees around the *X* axis, the commands are:

```
/gate/Name_Volume/placement/setRotationAxis X 0 0
/gate/Name_Volume/placement/setRotationAngle N deg
/gate/Name_Volume/placement/setAxis 0 1 0
```

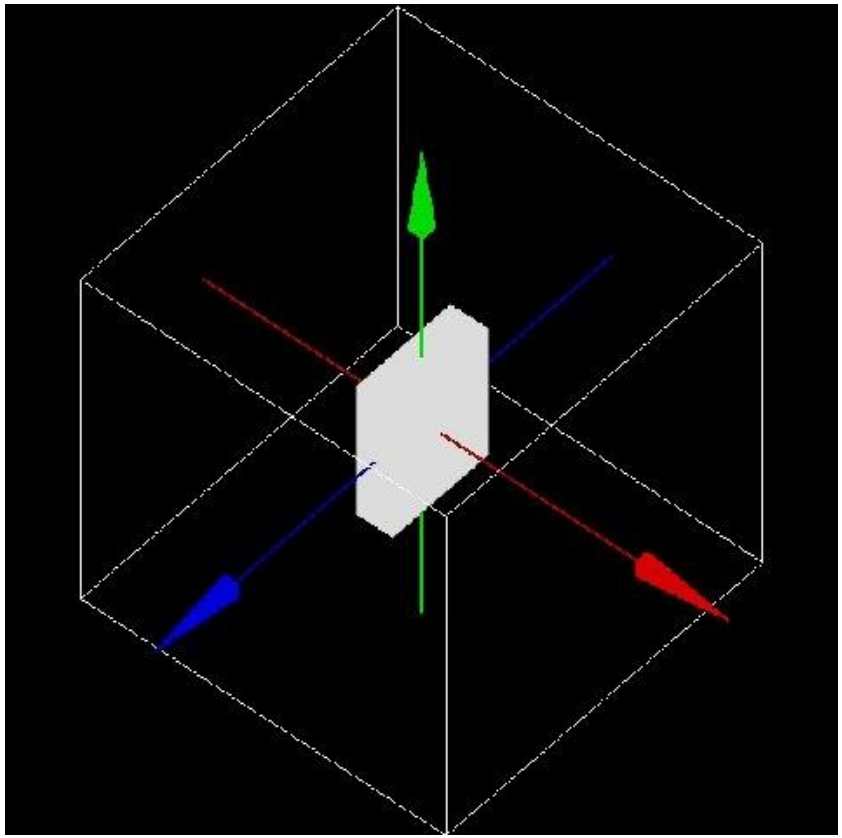
The default rotation axis is the Z axis.

- Example

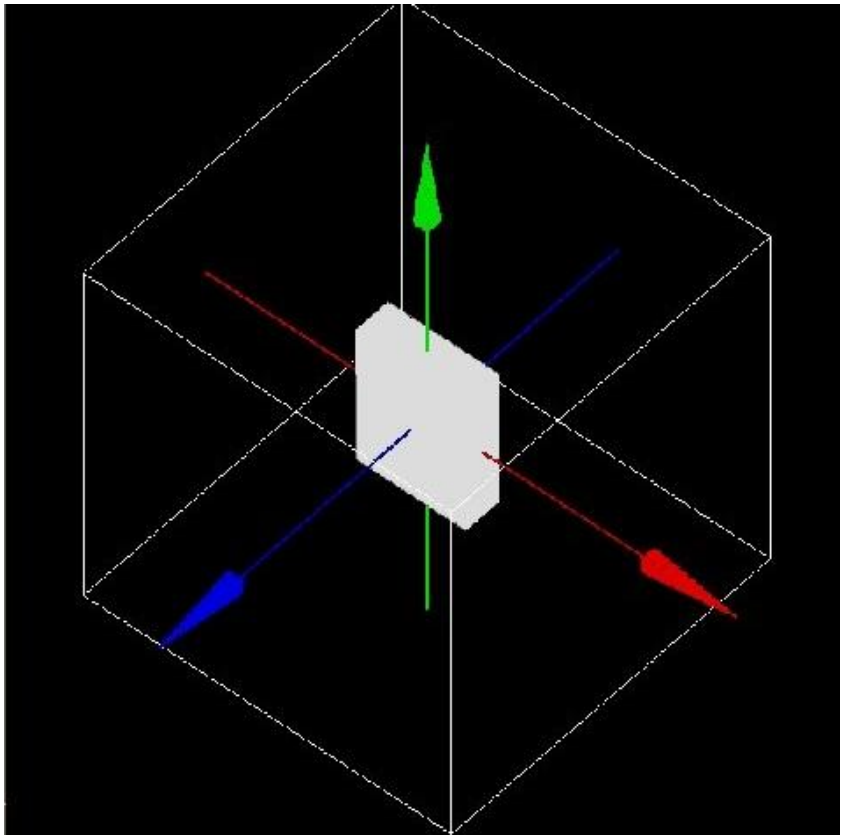
```
/gate/Phantom/placement/setRotationAxis 0 1 0
/gate/Phantom/placement/setRotationAngle 90 deg
```

Rotation (placement)

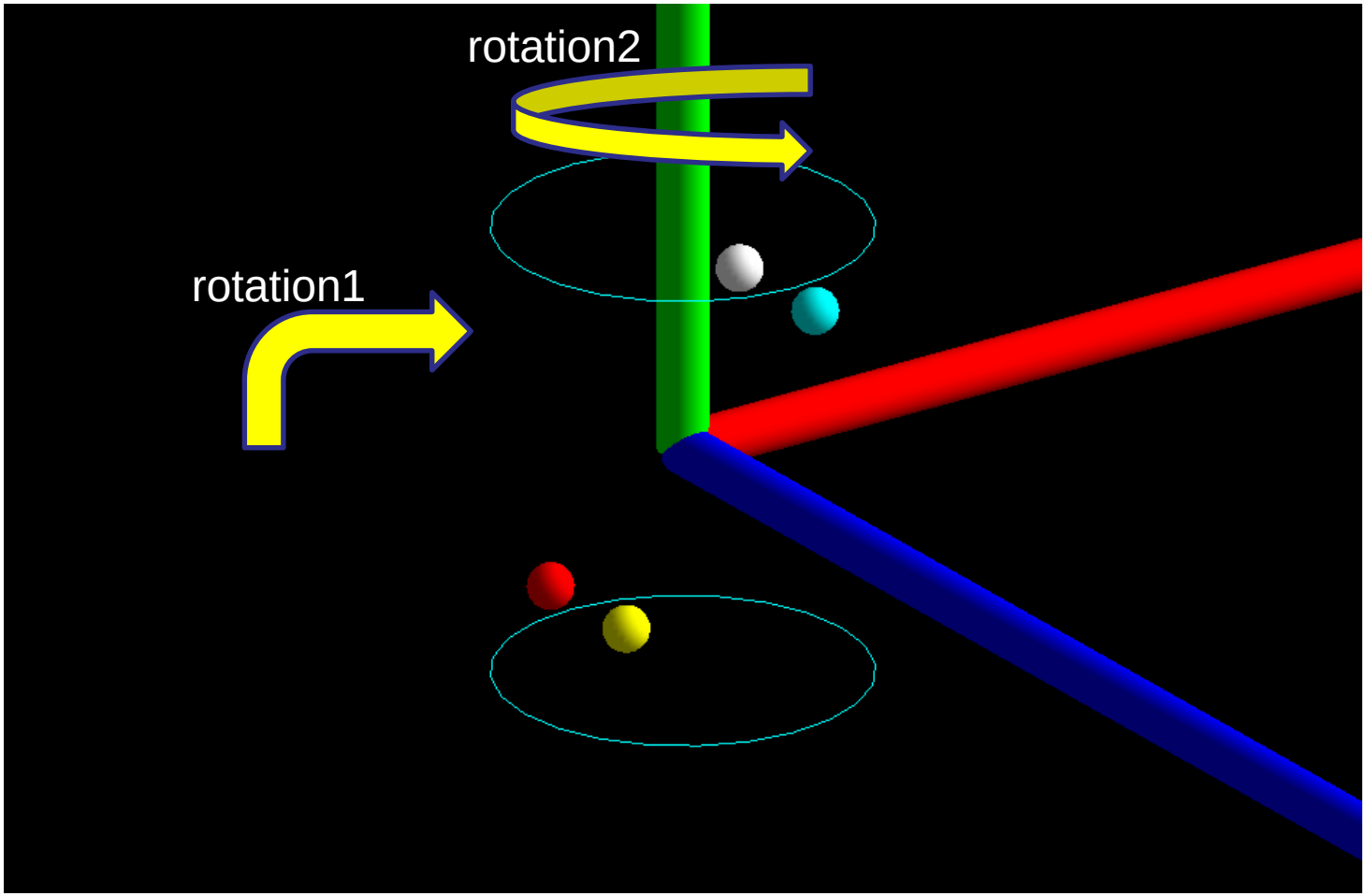
Original geometry



Rotation



Rotation (acquisition)



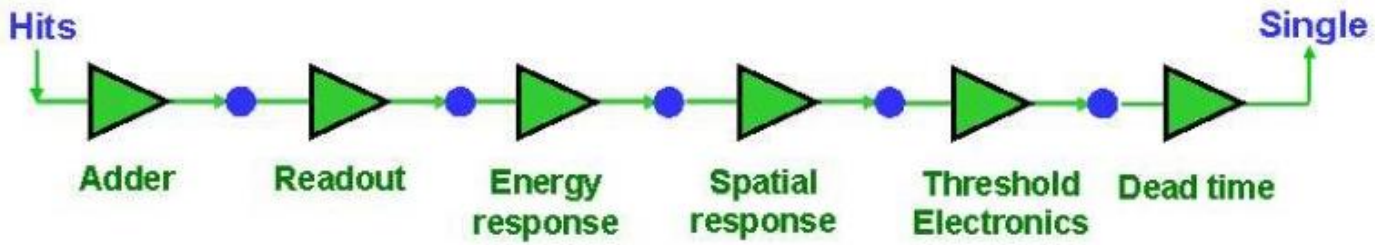
(3) DIGITIZER

Detector circuit

Digitizer.mac (Detector Circuit)

- The purpose of the digitizer module is to simulate the behavior of the scanner detectors and signal processing chain.
- Simulate a scanner electronic readout scheme.

- Role of the digitizer
  - As mentioned above, the information contained in the *hit* does not correspond to what is provided by a real detector. To simulate the digital values (*pulses*) that result from the output of the Front End Electronics, the sampling methods of the signal must be specified. To do this, a number of digitizer modules are available and are described below. Moreover, in the case of PET analysis, the trigger logic is based on one or more decisions defined by the user that depend upon physically observable quantities such as energy thresholds and coincidence times.



Digitizer.mac

- ############
- # DIGITIZER #
- ############
- /gate/digitizer/Singles/insert adder
- /gate/digitizer/Singles/insert readout
- /gate/digitizer/Singles/readout/setDepth 2
- /gate/digitizer/Singles/insert thresholder
- /gate/digitizer/Singles/thresholder/setThreshold 10 keV
- /gate/digitizer/convertor/verbose 0
- /gate/digitizer/verbose 0

- /gate/digitizer/Singles/insert spblurring
- /gate/digitizer/Singles/spblurring/setSpresolution 2.0 mm
- /gate/digitizer/Singles/spblurring/verbose 0

(4) PHYSICS MODEL

Physics model

Physics.mac

```
##############
# EM PROCESS #
##############
/gate/physics/addProcess PhotoElectric
/gate/physics/processes/PhotoElectric/setModel StandardModel

/gate/physics/addProcess Compton
/gate/physics/processes/Compton/setModel PenelopeModel

/gate/physics/addProcess RayleighScattering
/gate/physics/processes/RayleighScattering/setModel PenelopeModel

/gate/physics/addProcess ElectronIonisation
/gate/physics/processes/ElectronIonisation/setModel StandardModel e-

/gate/physics/addProcess Bremsstrahlung
/gate/physics/processes/Bremsstrahlung/setModel StandardModel e-

/gate/physics/addProcess MultipleScattering e-

/gate/physics/processList Enabled
/gate/physics/processList Initialized
```

Physics processes

- EM processes
  - Standard and low energy EM processes available
    - Photoelectric, Compton scattering, Rayleigh scattering, pair production
    - Ionization (for e-, e+, hadrons, ions..)
    - Bremsstrahlung, positron and e- anihilation, single and multiple scattering
- Hadronic processes
  - Elastic scattering
  - Inelastic process for proton, ion
  - Pions, neutrons, particle decay, radioactice decay

(5) ACQUISITION

Acquire result images

acquisition.mac

- ################################
- # ACQUISITION for 1 projection #
- ################################
- /gate/application/setTimeSlice 45. s
- /gate/application/setTimeStart 0. s
- /gate/application/setTimeStop 180. s

- ###################################
- # ACQUISITION with 360 projections #
- ###################################
- #/gate/application/setTimeSlice 1. s
- #/gate/application/setTimeStart 0. s
- #/gate/application/setTimeStop 360. s

- /gate/application/startDAQ

(6) RADIATION SOURCE

Generate primary beams.

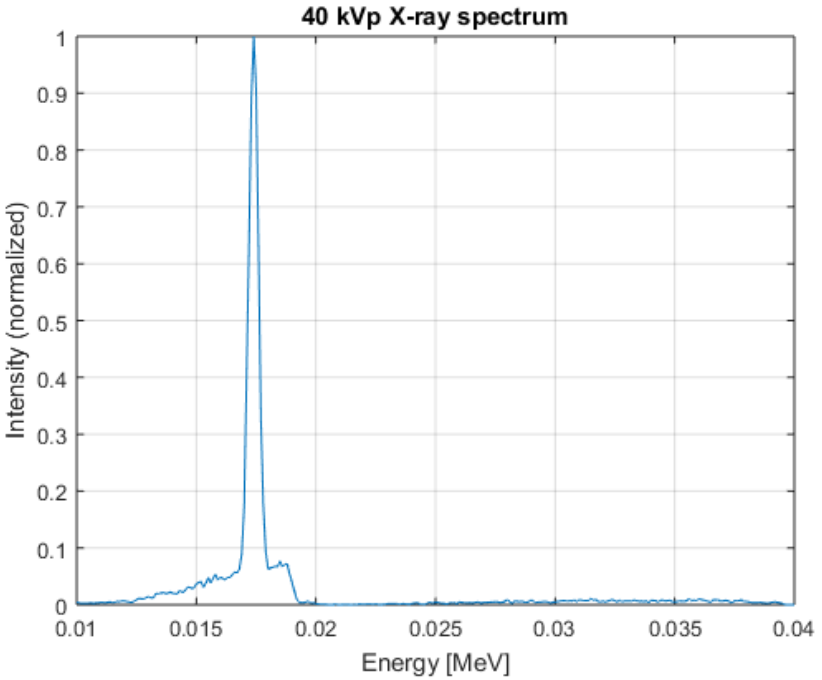
Source.mac

- /gate/source/addSource xraygun
- /gate/source/verbose 0
- /gate/source/xraygun/setActivity 350000. becquerel
- /gate/source/xraygun/gps/verbose 0
- /gate/source/xraygun/gps/particle gamma
- /gate/source/xraygun/gps/energytype Arb
- /gate/source/xraygun/gps/histname arb
- /gate/source/xraygun/gps/emin 10.00 keV
- /gate/source/xraygun/gps/emax 40.00 keV
- /gate/source/xraygun/gps/histpoint 0.0100 7
- /gate/source/xraygun/gps/histpoint 0.0102 4
- /gate/source/xraygun/gps/histpoint 0.0104 4
- /gate/source/xraygun/gps/histpoint 0.0105 4

  .

  .

  .
- /gate/source/xraygun/gps/histpoint 0.0394 5
- /gate/source/xraygun/gps/histpoint 0.0395 4
- /gate/source/xraygun/gps/histpoint 0.0396 0
- /gate/source/xraygun/gps/histpoint 0.0397 0
- /gate/source/xraygun/gps/histpoint 0.0398 0
- /gate/source/xraygun/gps/histpoint 0.0399 0
- /gate/source/xraygun/gps/histpoint 0.0400 0
- /gate/source/xraygun/gps/arbint Lin
- /gate/source/xraygun/gps/type Plane
- /gate/source/xraygun/gps/shape Rectangle
- /gate/source/xraygun/gps/halfx 0.025 mm
- /gate/source/xraygun/gps/halfy 0.025 mm
- /gate/source/xraygun/gps/mintheta 0 deg
- /gate/source/xraygun/gps/maxtheta 6.8 deg
- /gate/source/xraygun/gps/centre 0. 0. -15.0 cm
- /gate/source/xraygun/gps/angtype iso
- /gate/source/list



General particle source (GPS)

- Point

  E.g.
  ```
  /gps/pos/type Point
  /gps/pos/centre 0. 0. 0. cm
  ```

- Beam

  E.g.
  ```
  /gps/pos/type Beam
  /gps/pos/shape Circle
  /gps/pos/radius 1. mm
  /gps/pos/sigma_r 2. mm
  ```

- Plane
  - Shape: Circle, Annulus, Ellipsoid, Square or Rectangle

  E.g.
  ```
  /gps/pos/type Plane
  /gps/pos/shape Rectangle
  /gps/pos/halfx 50 cm
  /gps/pos/halfy 70 cm
  ```

- Surface or Volume
  - Shape: Sphere, Ellipsoid, Cylinder or Para
  - Surface: zenith automatically oriented as normal to surface at point

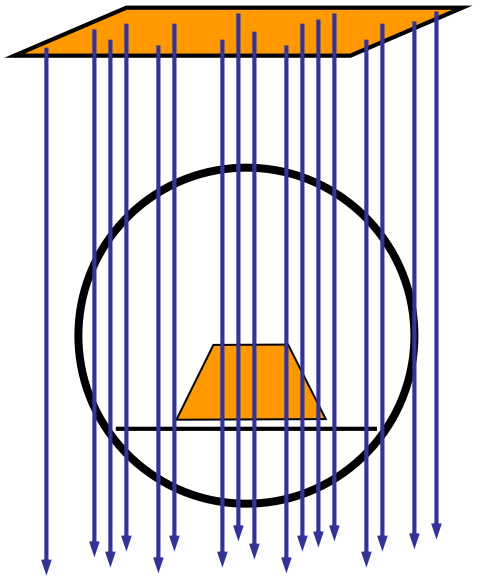
  E.g.
  ```
  /gps/pos/type Surface
  /gps/pos/shape Sphere
  /gps/pos/radius 1. m
  ```

Example: proton source of exercises jour 2a 2b 2c

- Vertices on rectangle along **xz** at edge of World
- Parallel emission along **-y**
- Monoenergetic: **500 MeV**

- Macro

```
/gps/particle proton

/gps/ene/type Mono
/gps/ene/mono 500 MeV

/gps/pos/type Plane
/gps/pos/shape Rectangle
/gps/pos/rot1 0 0 1
/gps/pos/rot2 1 0 0
/gps/pos/halfx 46.2 cm
/gps/pos/halfy 57.2 cm
/gps/pos/centre 0. 57.2 0. cm

/gps/direction 0 -1 0
```



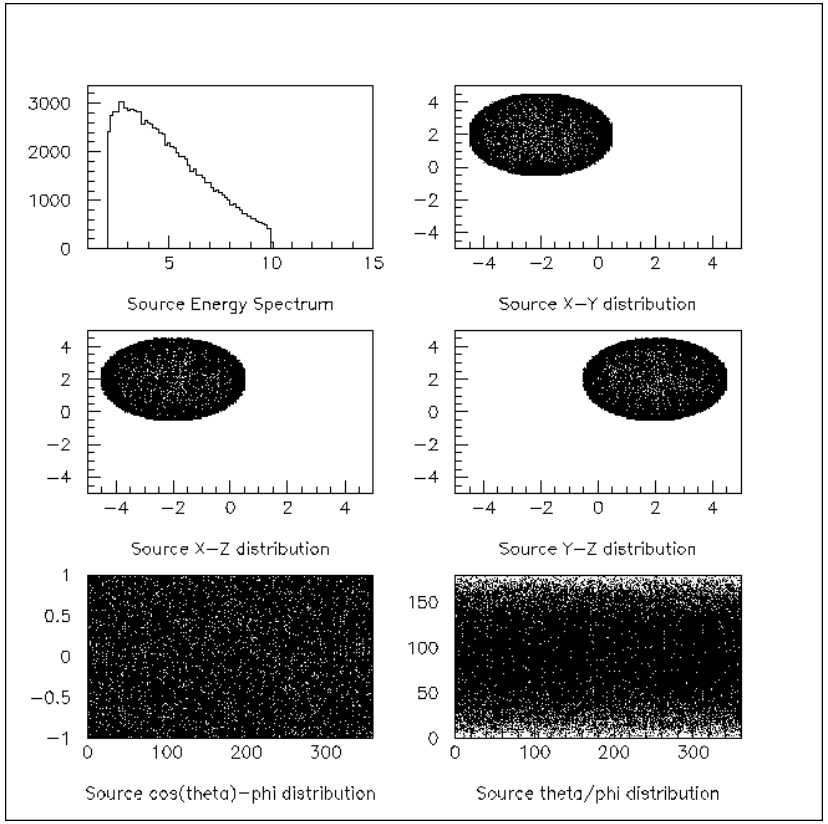
GPS

Example 6

- Vertex on sphere surface
- Isotropic emission
- Pre-defined spectrum (black-body)

Macro

```
/gps/particle geantino

/gps/pos/type Surface
/gps/pos/shape Sphere
/gps/pos/centre -2. 2. 2. cm
/gps/pos/radius 2.5 cm

/gps/ang/type iso

/gps/ene/type Bbody
/gps/ene/min 2. MeV
/gps/ene/max 10. MeV
/gps/ene/temp 2e10
/gps/ene/calculate
```



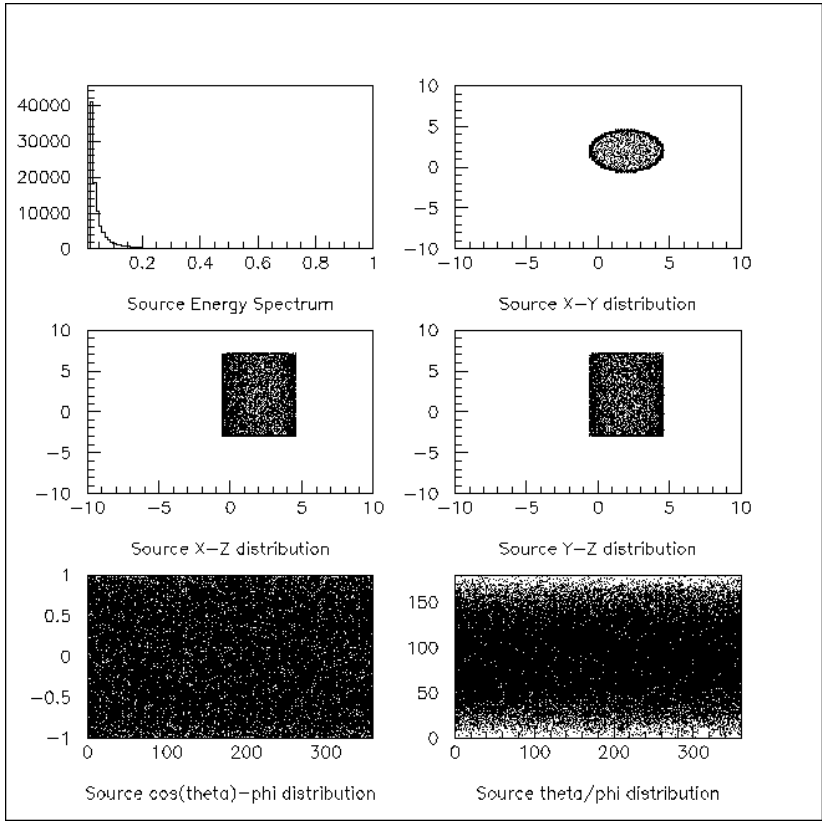
GPS

Example 7

- Vertex on cylinder surface
- Cosine-law emission
  (to mimic isotropic source in space)
- Pre-defined spectrum
  (Cosmic Diffuse Gamma)

Macro

```
/gps/particle gamma

/gps/pos/type Surface
/gps/pos/shape Cylinder
/gps/pos/centre 2. 2. 2. cm
/gps/pos/radius 2.5 cm
/gps/pos/halfz 5. cm

/gps/ang/type cos

/gps/ene/type Cdg
/gps/ene/min 20. keV
/gps/ene/max 1. MeV
/gps/ene/calculate
```



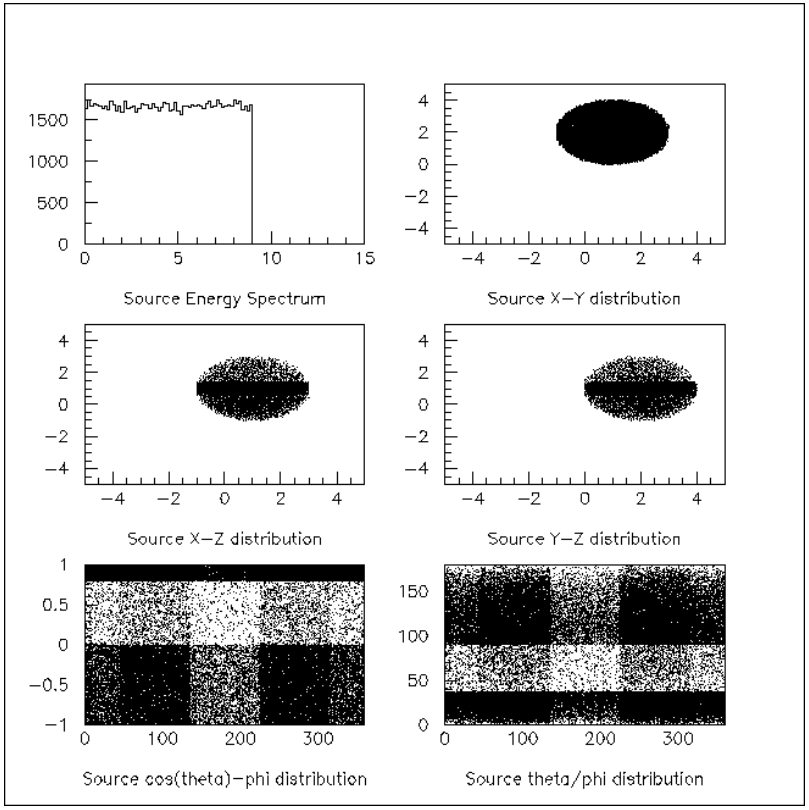
GPS

Example 24

- Vertex in sphere volume with z biasing
- Isotropic radiation with theta and phi biasing
- Integral arbitrary point-wise energy distribution with linear interpolation.

- Macro

```
/gps/particle geantino
/gps/pos/type Volume
/gps/pos/shape Sphere
/gps/pos/centre 1. 2. 1. cm
/gps/pos/radius 2. Cm

/gps/ang/type iso

/gps/ene/type Arb
/gps/ene/diffspec 0
/gps/hist/type arb
/gps/hist/point 0.0 11.
/gps/hist/point 1.0 10.
/gps/hist/point 2.0 9.
/gps/hist/point 3.0 8.
/gps/hist/point 4.0 7.
/gps/hist/point 7.0 4.
/gps/hist/point 8.0 3.
/gps/hist/point 9.0 2.
/gps/hist/point 10.0 1.
/gps/hist/point 11.0 0.
/gps/hist/inter Lin

/gps/hist/type biasz
/gps/hist/point 0. 0.
/gps/hist/point 0.4 0.5
/gps/hist/point 0.6 1.
/gps/hist/point 1. 0.2

/gps/hist/type biast
/gps/hist/point 0. 0.
/gps/hist/point 0.1 1.
/gps/hist/point 0.5 0.1
/gps/hist/point 1. 1.

/gps/hist/type biasp
/gps/hist/point 0. 0.
/gps/hist/point 0.125 1.
/gps/hist/point 0.375 4.
/gps/hist/point 0.625 1.
/gps/hist/point 0.875 4.
/gps/hist/point 1. 1.
```



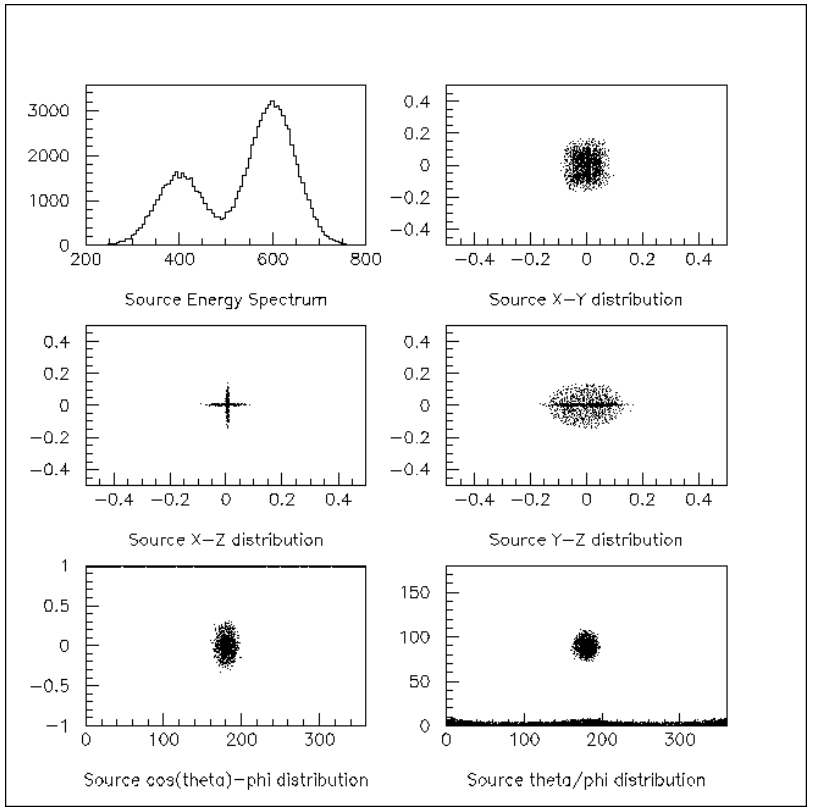
GPS

Example 31

- Two-beam source definition (multiple sources)
- Gaussian profile
- Can be focused / defocused

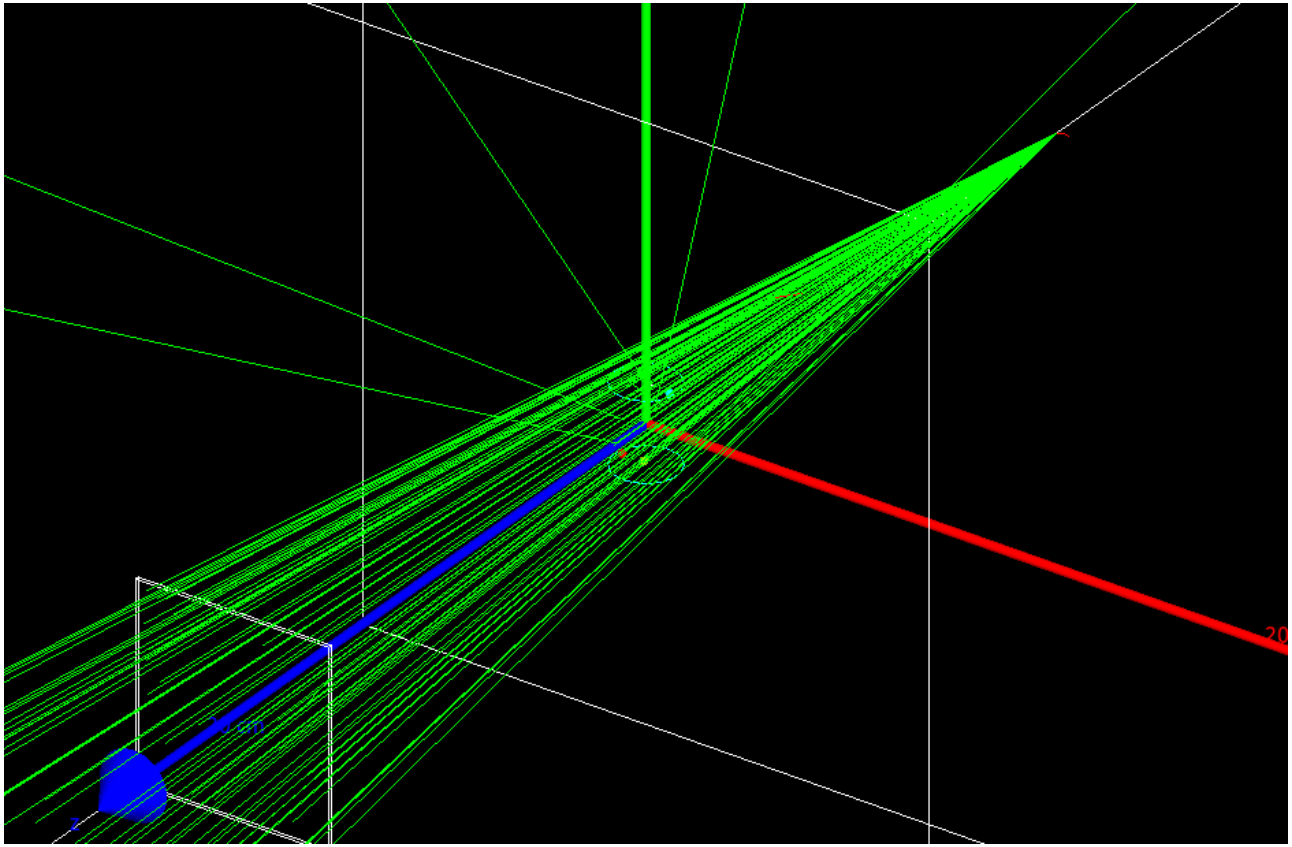
- Macro

```
# beam #1
  # default intensity is 1,
  # now change to 5.
  /gps/source/intensity 5.

  /gps/particle proton
  /gps/pos/type Beam

  # the incident surface is
  # in the y-z plane
  /gps/pos/rot1 0 1 0
  /gps/pos/rot2 0 0 1

  # the beam spot is centered
  # at the origin and is
  # of 1d gaussian shape
  # with a 1 mm central plateau
  /gps/pos/shape Circle
  /gps/pos/centre 0. 0. 0. mm
  /gps/pos/radius 1. mm
  /gps/pos/sigma_r .2 mm

  # the beam is travelling
  # along the X_axis
  # with 5 degrees dispersion
  /gps/ang/rot1 0 0 1
  /gps/ang/rot2 0 1 0
  /gps/ang/type beam1d
  /gps/ang/sigma_r 5. deg

  # the beam energy is in
  # gaussian profile centered
  # at 400 MeV
  /gps/ene/type Gauss
  /gps/ene/mono 400 MeV
  /gps/ene/sigma 50. MeV

# beam #2
  # 2x the instensity of beam #1
  /gps/source/add 10.

  # this is a electron beam
  ...
```



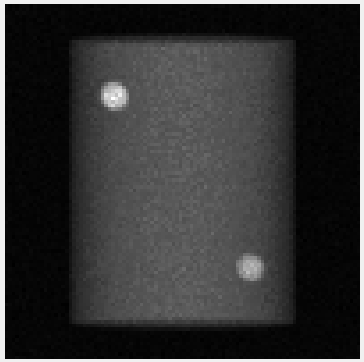
Beam-on

- @ run.mac
- # HandsOn #5
- # Run Monte-carlo simulation
- /control/execute acquisition.mac

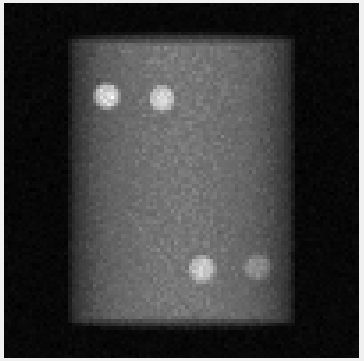


Result

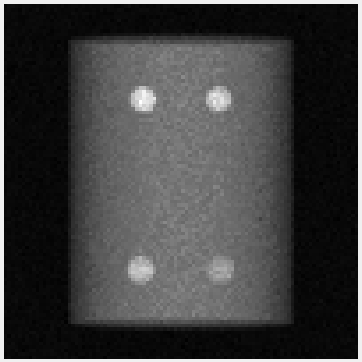
0 degree



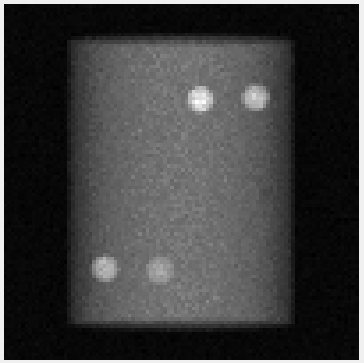
45 degree



90 degree



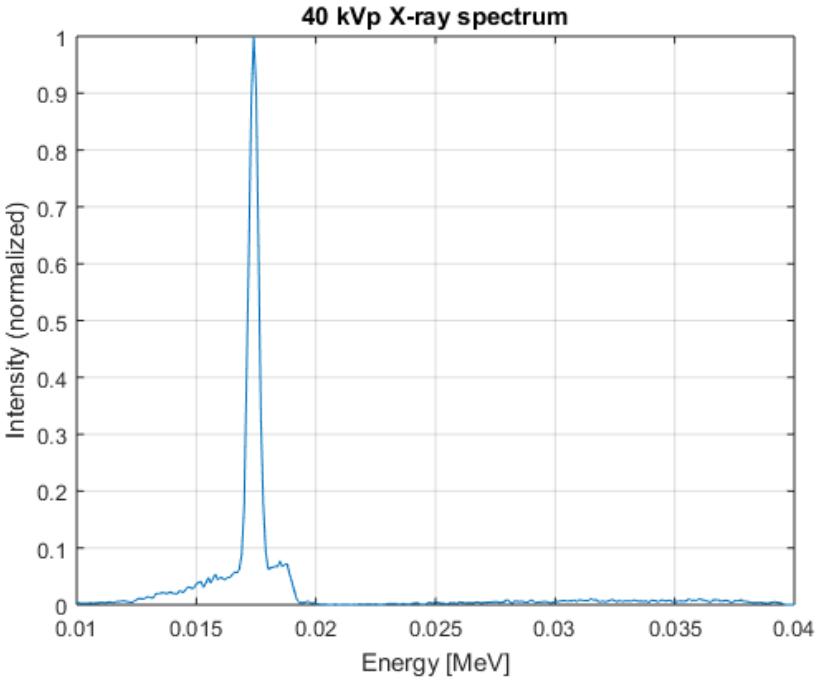
135 degree



III. Advanced MYCT-example

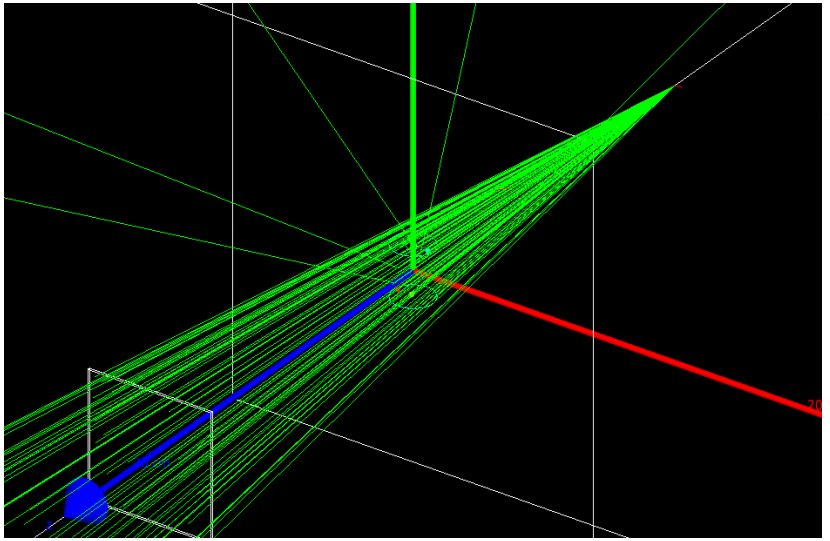
Source.mac

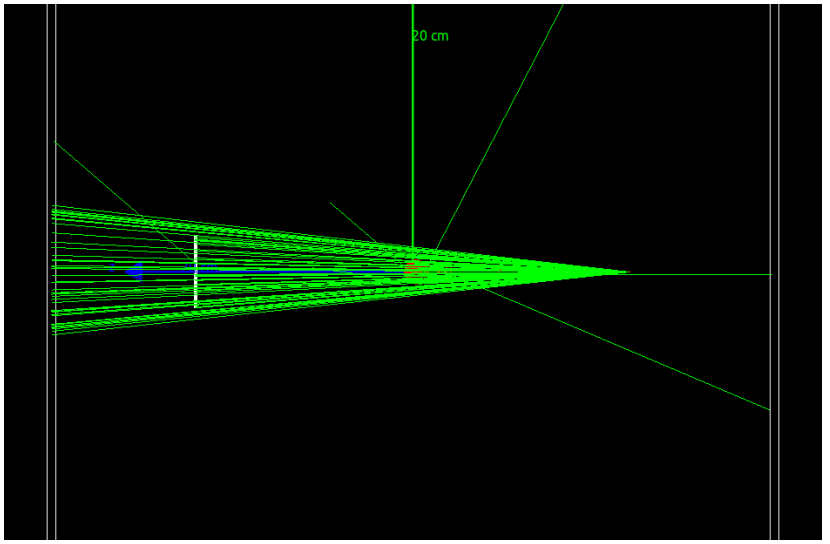
- /gate/source/addSource xraygun
- /gate/source/verbose 0
- /gate/source/xraygun/setActivity 350000. becquerel
- /gate/source/xraygun/gps/verbose 0
- /gate/source/xraygun/gps/particle gamma
- /gate/source/xraygun/gps/energytype Arb
- /gate/source/xraygun/gps/histname arb
- /gate/source/xraygun/gps/emin 10.00 keV
- /gate/source/xraygun/gps/emax 40.00 keV
- /gate/source/xraygun/gps/histpoint 0.0100 7
- /gate/source/xraygun/gps/histpoint 0.0102 4
- /gate/source/xraygun/gps/histpoint 0.0104 4
- /gate/source/xraygun/gps/histpoint 0.0105 4
- .
- .
- .
- .
- /gate/source/xraygun/gps/histpoint 0.0394 5
- /gate/source/xraygun/gps/histpoint 0.0395 4
- /gate/source/xraygun/gps/histpoint 0.0396 0
- /gate/source/xraygun/gps/histpoint 0.0397 0
- /gate/source/xraygun/gps/histpoint 0.0398 0
- /gate/source/xraygun/gps/histpoint 0.0399 0
- /gate/source/xraygun/gps/histpoint 0.0400 0
- /gate/source/xraygun/gps/arbint Lin
- /gate/source/xraygun/gps/type Plane
- /gate/source/xraygun/gps/shape Rectangle
- /gate/source/xraygun/gps/halfx 0.025 mm
- /gate/source/xraygun/gps/halfy 0.025 mm
- /gate/source/xraygun/gps/mintheta 0 deg
- /gate/source/xraygun/gps/maxtheta 6.8 deg
- /gate/source/xraygun/gps/centre 0. 0. -15.0 cm
- /gate/source/xraygun/gps/angtype iso
- /gate/source/list



Source.mac

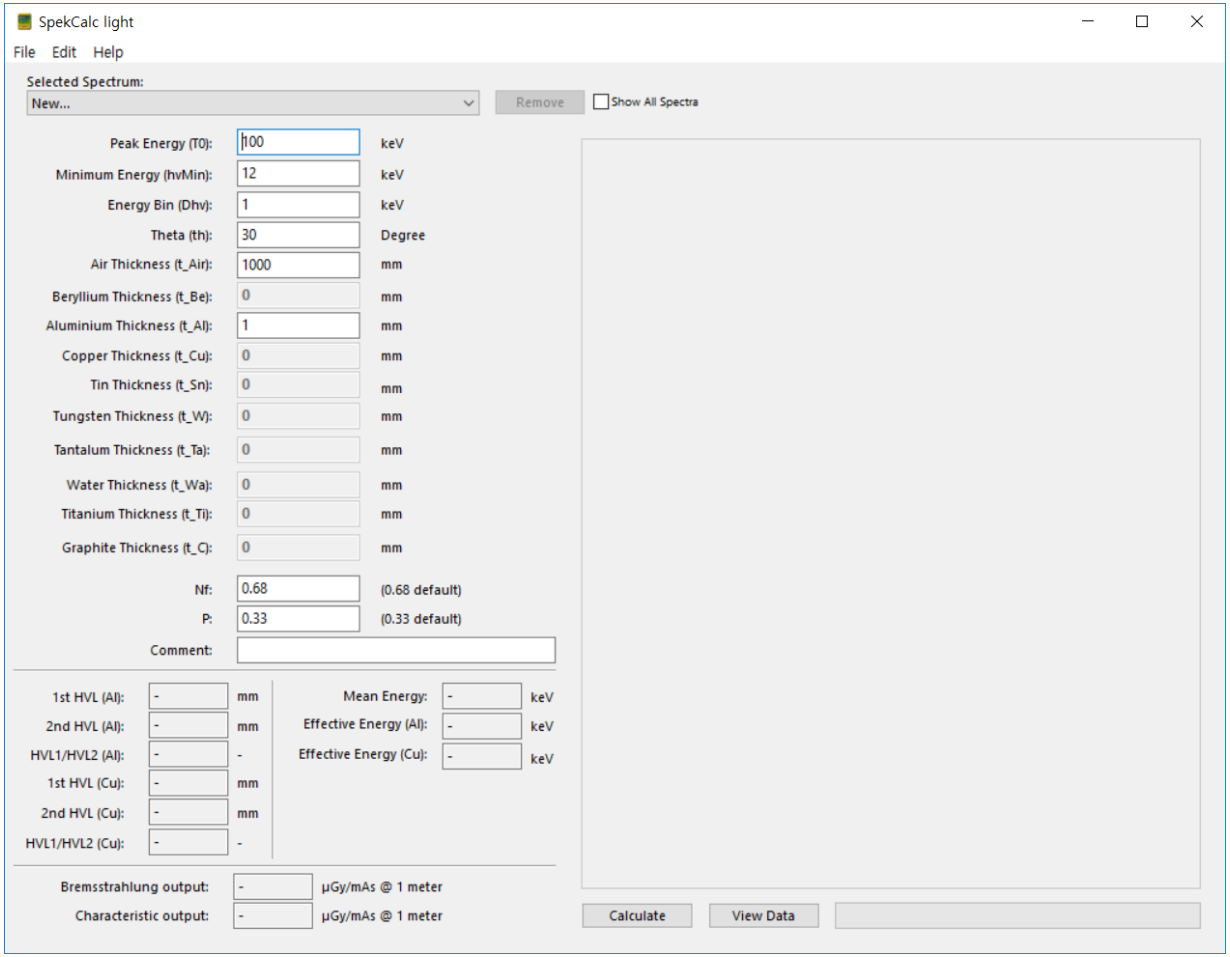
- /gate/source/addSource xraygun
- /gate/source/verbose 0
- /gate/source/xraygun/setActivity 350000. becquerel
- /gate/source/xraygun/gps/verbose 0
- /gate/source/xraygun/gps/particle gamma
- /gate/source/xraygun/gps/energytype Arb
- /gate/source/xraygun/gps/histname arb
- /gate/source/xraygun/gps/emin 10.00 keV
- /gate/source/xraygun/gps/emax 40.00 keV
- /gate/source/xraygun/gps/histpoint 0.0100 7
- /gate/source/xraygun/gps/histpoint 0.0102 4
- /gate/source/xraygun/gps/histpoint 0.0104 4
- /gate/source/xraygun/gps/histpoint 0.0105 4
- .
- .
- .
- .
- /gate/source/xraygun/gps/histpoint 0.0394 5
- /gate/source/xraygun/gps/histpoint 0.0395 4
- /gate/source/xraygun/gps/histpoint 0.0396 0
- /gate/source/xraygun/gps/histpoint 0.0397 0
- /gate/source/xraygun/gps/histpoint 0.0398 0
- /gate/source/xraygun/gps/histpoint 0.0399 0
- /gate/source/xraygun/gps/histpoint 0.0400 0
- /gate/source/xraygun/gps/arbint Lin
- /gate/source/xraygun/gps/type Plane
- /gate/source/xraygun/gps/shape Rectangle
- /gate/source/xraygun/gps/halfx 0.025 mm
- /gate/source/xraygun/gps/halfy 0.025 mm
- /gate/source/xraygun/gps/mintheta 0 deg
- /gate/source/xraygun/gps/maxtheta 6.8 deg
- /gate/source/xraygun/gps/centre 0. 0. -15.0 cm
- /gate/source/xraygun/gps/angtype iso
- /gate/source/list



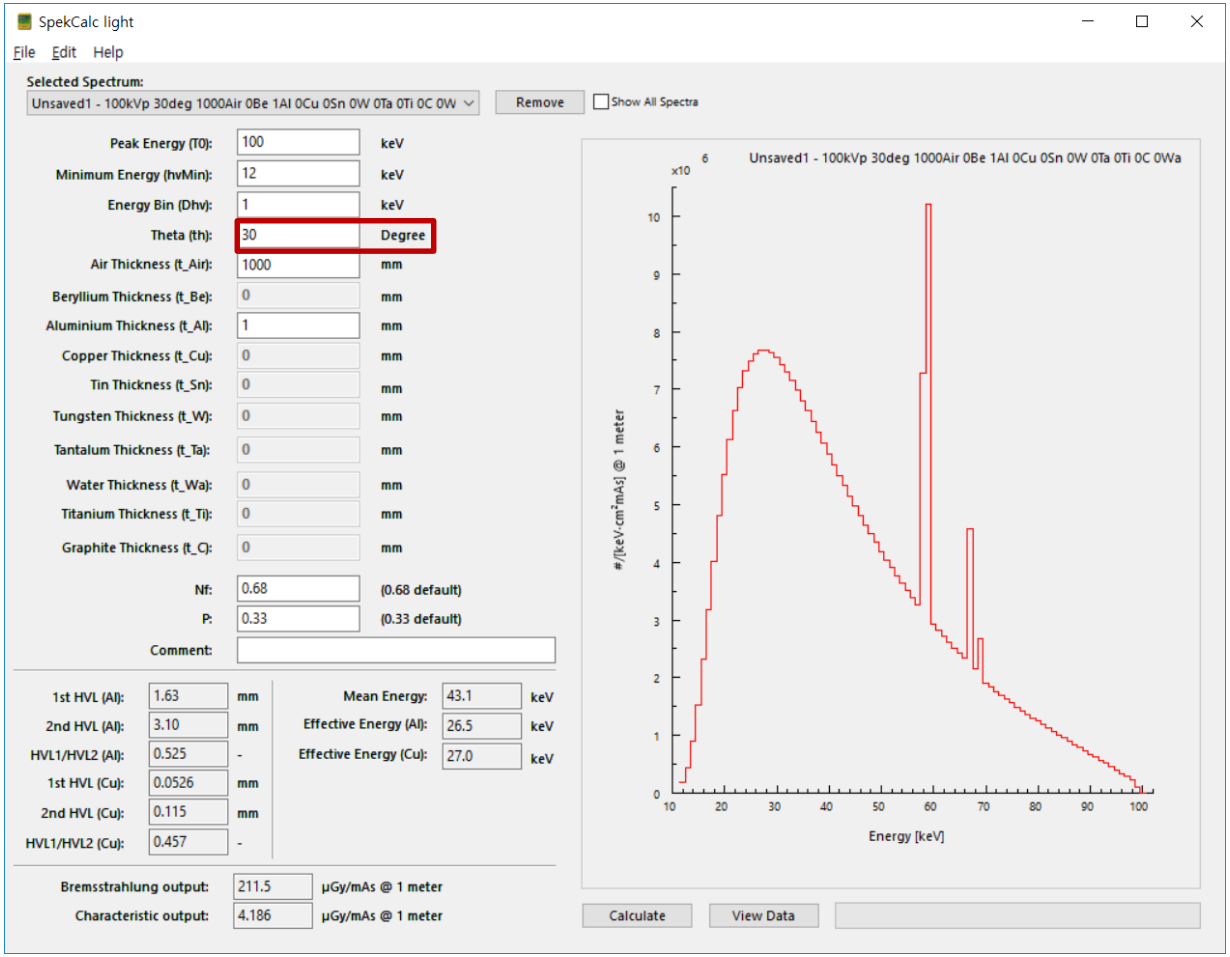


Generate spectrum

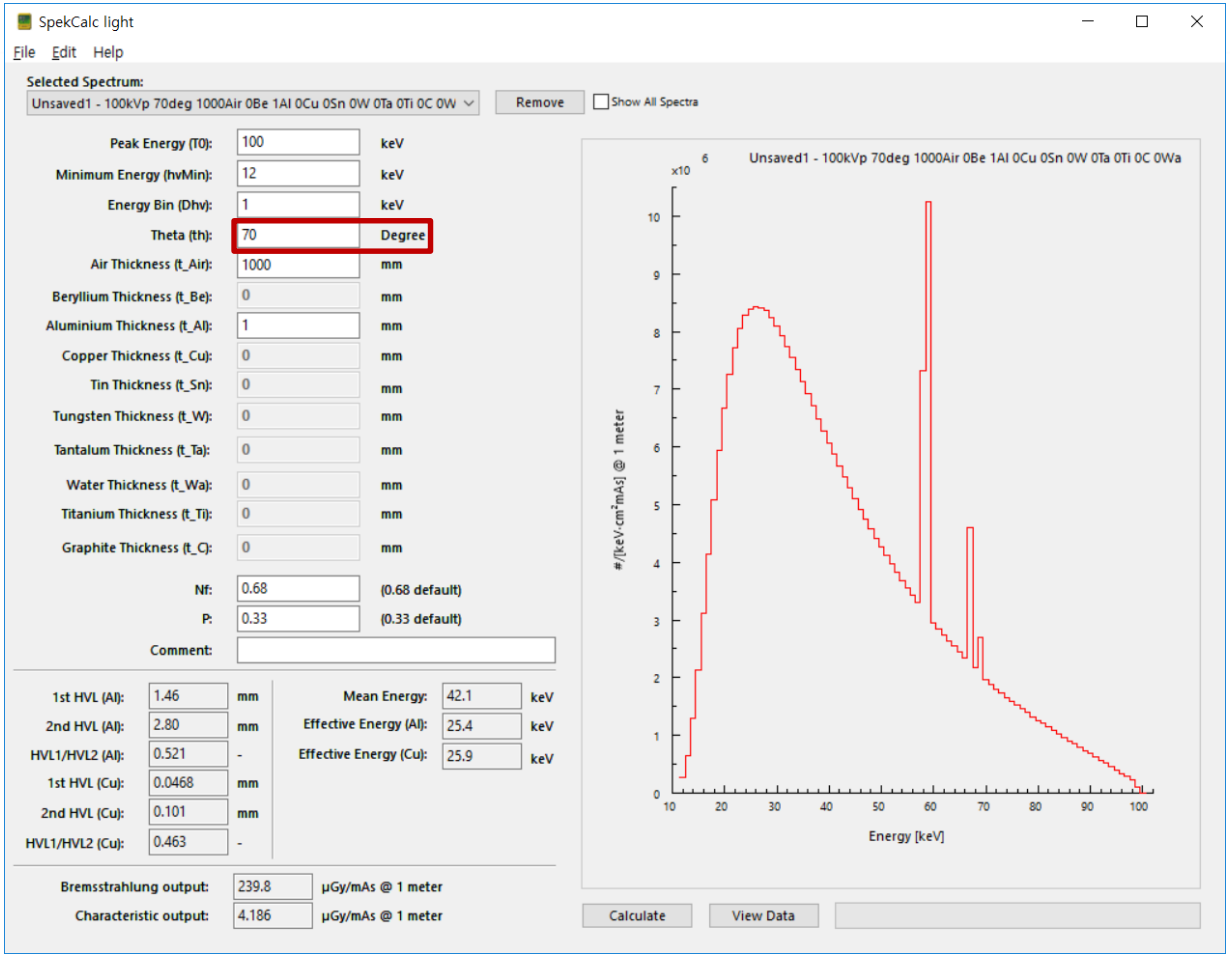
:SpekCalc light



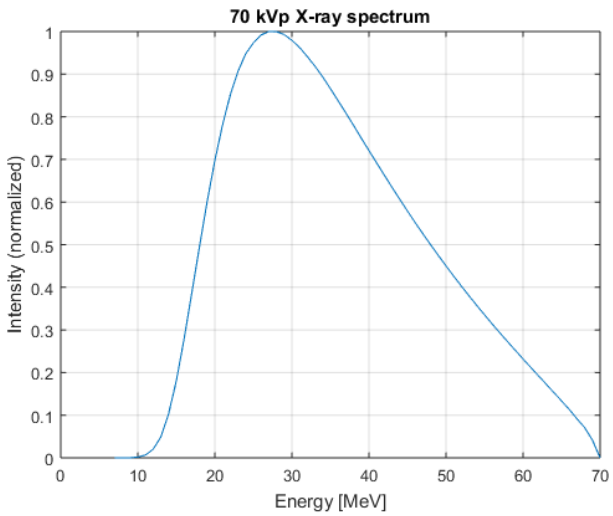
Generate spectrum
:SpekCalc light

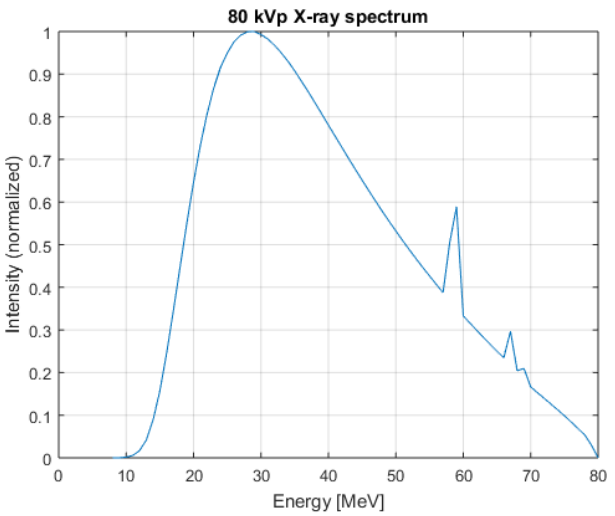


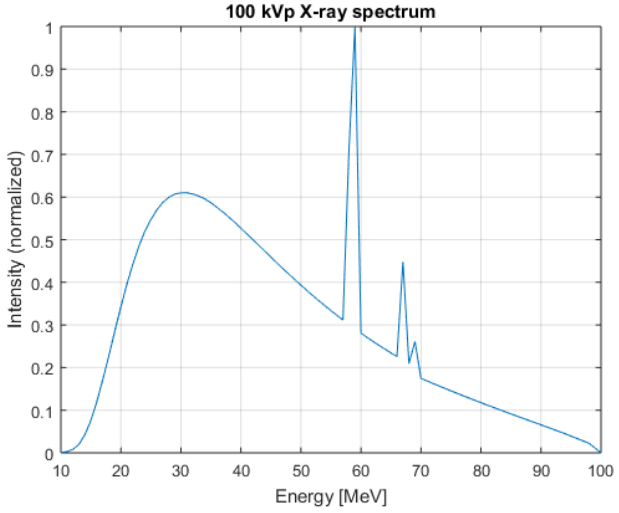
Generate spectrum
:SpekCalc light

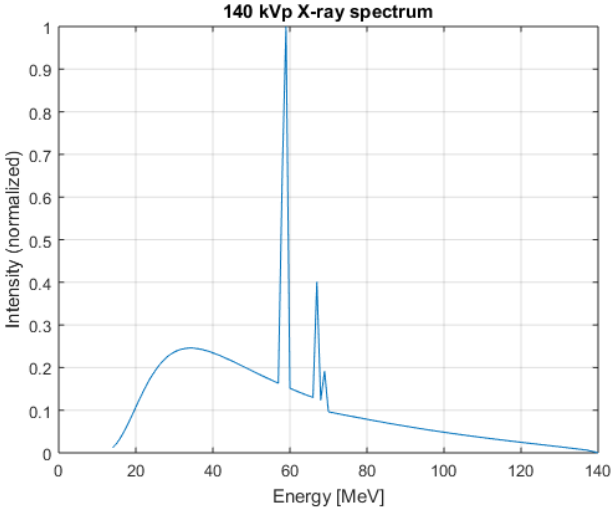


Result









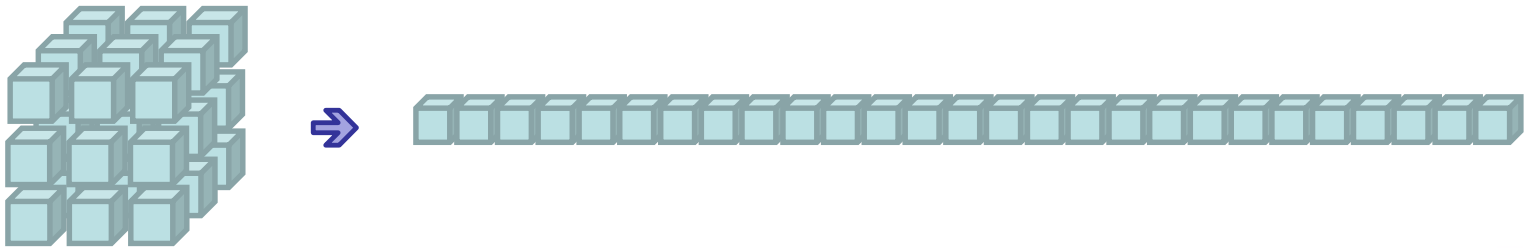
Archive → https://github.com/wjcheon/SpectrumGeneratorForMC_Matlab

Process of
inserting DICOM image to phantom

Step1
- Read dicom images
- Convert 3D Matrix to 1D vector
- 1 x n dimensional vector

Step2
- Write image as binary (int16, short) [*.img]
- Write header for gate reading class [*.mhd]

Step3
- Insert Dicom to Gate



*.mhd (header)

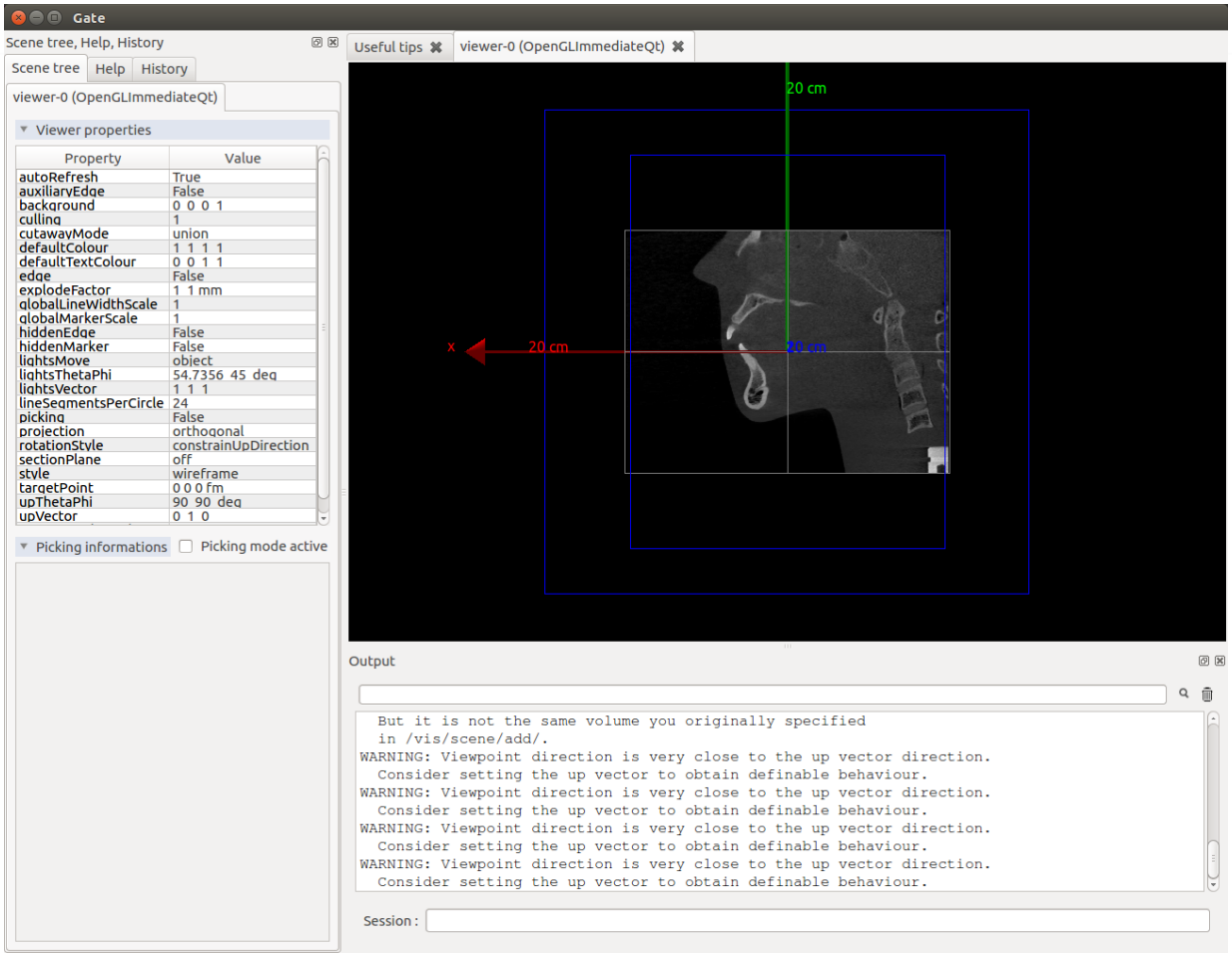
- ObjectType = Image
- NDims = 3
- BinaryData = Ture
- BinaryDataByteOrderMSB = False
- CompressedData = False
- TransformMatrix = 1 0 0 0 1 0 0 0 1
- Offset = 0 0 0
- CenterOfRotation = 0 0 0
- AnatomicalOrientation = RAI
- ElementSpacing = 1.2 1.2 1.2
- DimSize = 202 202 126
- ElementType = MET_SHORT
- ElementDataFile = Realskull-quater_0.raw

Run.mac

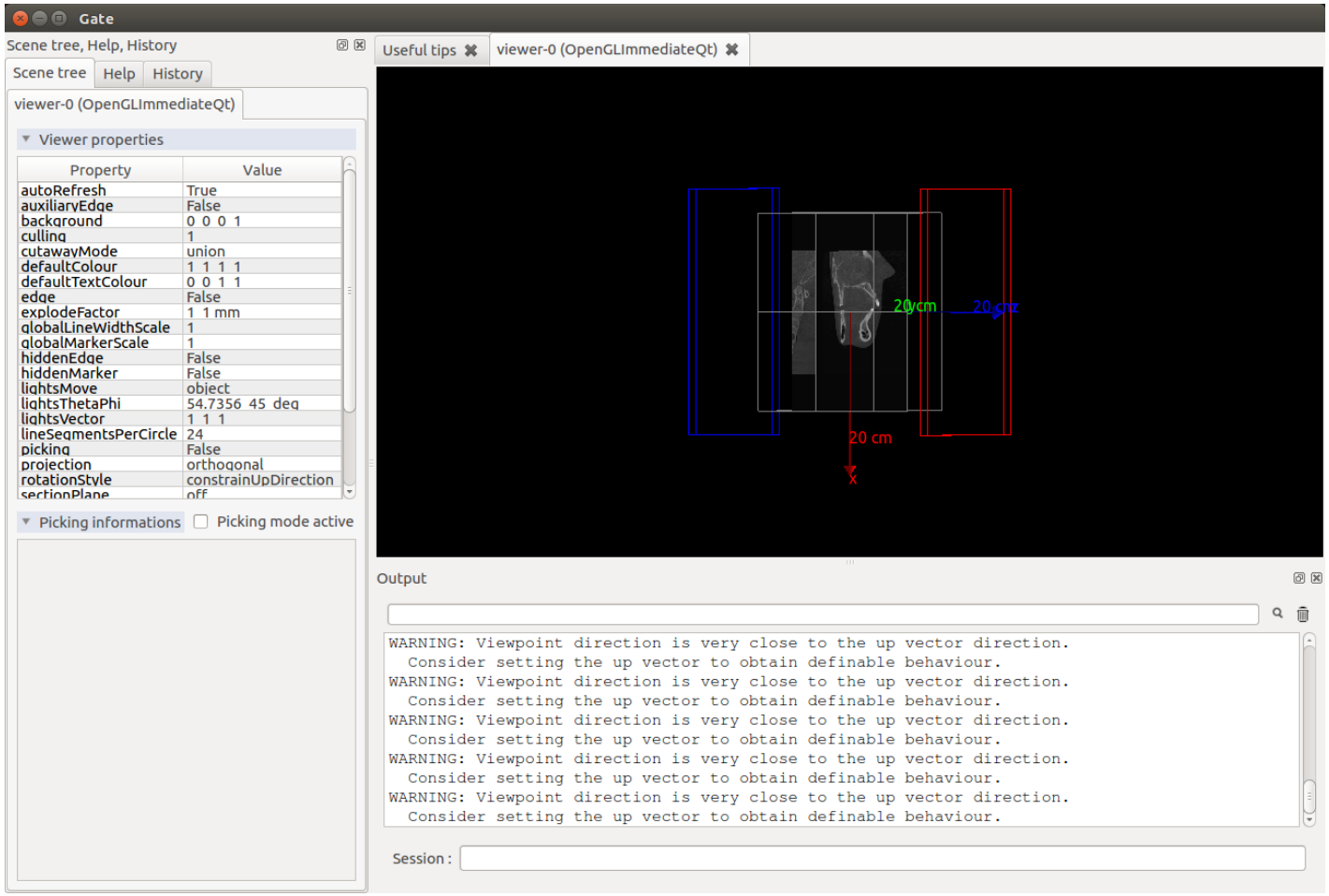
- @run.mac
- HandsOn #3 → 주석처리
- HandsOn #4 → 주석처리
- # HandsOn #6 → 주석제거
- # Define VoxelPhantoms
- /gate/world/daughters/name Voxel
- /gate/world/daughters/insert ImageNestedParameterisedVolume
- /gate/Voxel/geometry/setHUToMaterialFile MaterialDB/patient-HU2mat.txt
- /gate/Voxel/geometry/setImage /Phantoms/Realskull-quarter_0.mhd

- # HandsOn #1
- # Set material database
- /gate/geometry/setMaterialDatabse ./MaterialDB/GateMaterials.db
- /gate/geometry/setMaterialDatabse ./MaterialDB/patient-HUmaterials.db
- #/gate/geometry/setMaterialDatabse ./MaterialDB/GateMaterials_modified.db

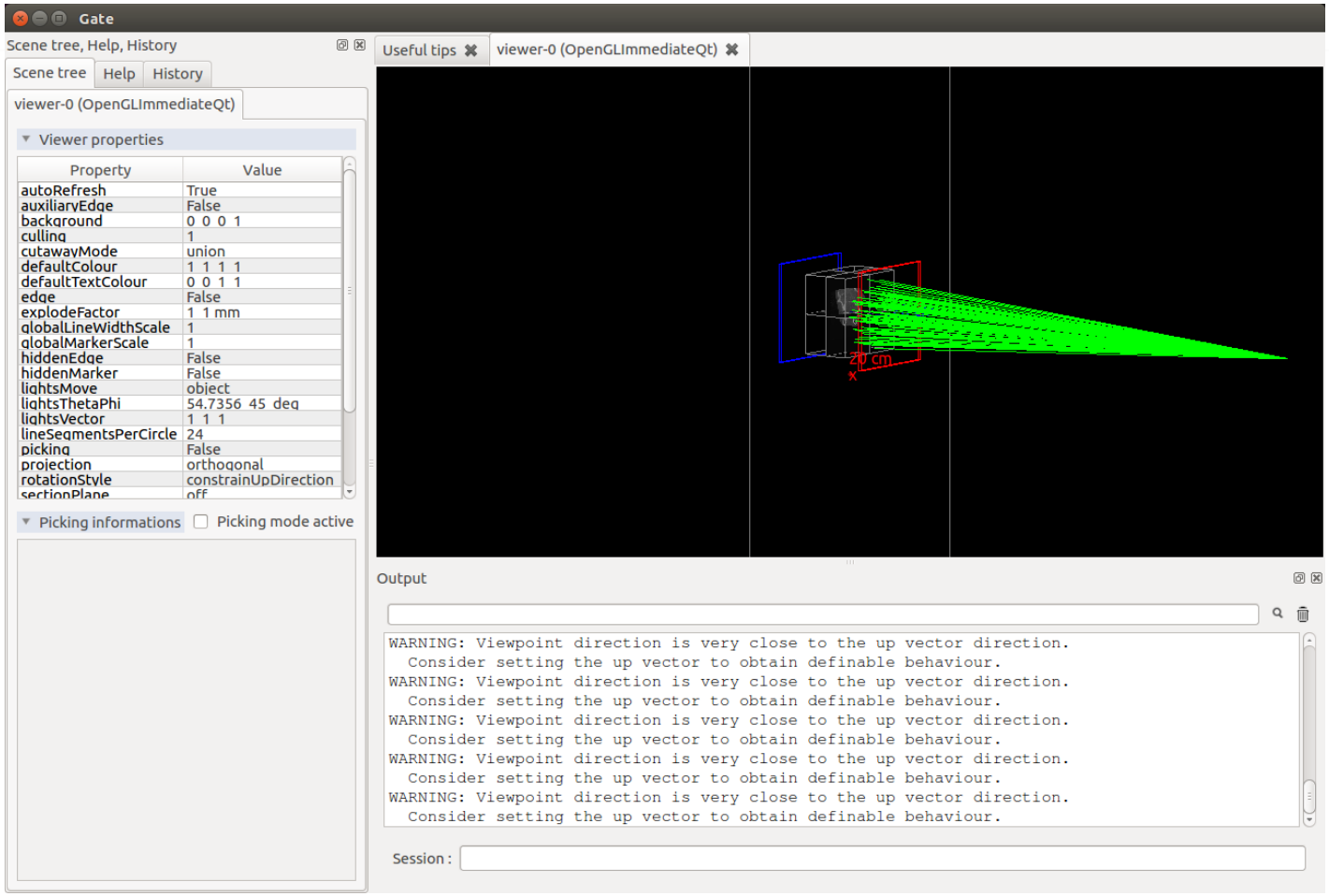
Dicom to Gate



Dicom to Gate



Dicom to Gate



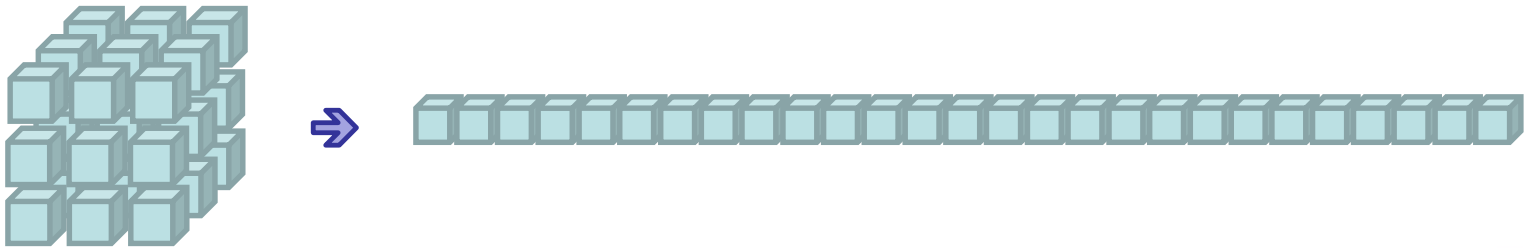
Result

Process of
inserting Matlab matrix to phantom

Step1
- Generate 3D phantom using Matlab
- Convert 3D Matrix to 1D vector
- 1 x n dimensional vector

Step 2
- Write image as binary (int16, short)
- Write header for gate reading class

Step 3
- Insert Phantom to Gate

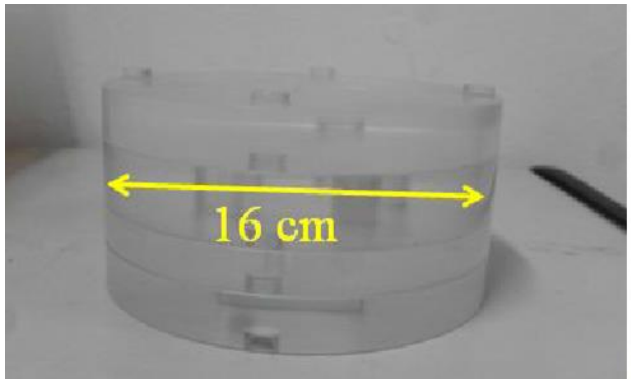


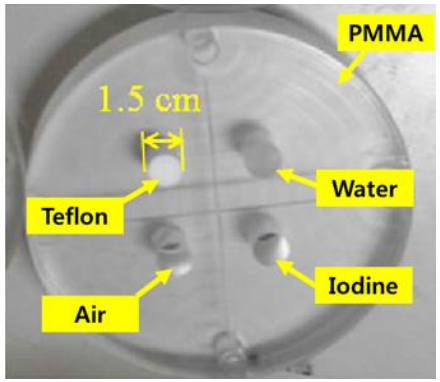
Run.mac

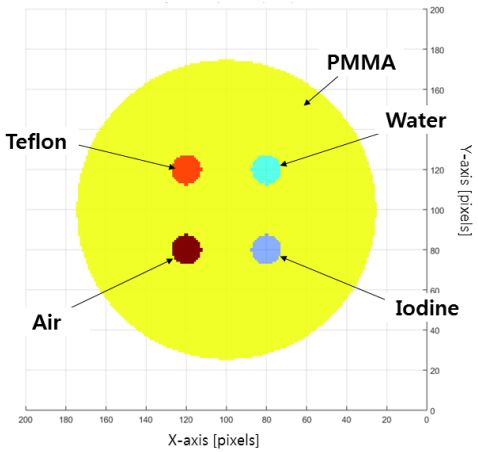
- @run.mac
- HandsOn #3 → 주석처리
- HandsOn #4 → 주석처리
- # HandsOn #7 → 주석제거
- # Define VoxelPhantoms
- /gate/world/daughters/name Voxel
- /gate/world/daughters/insert ImageNestedParameterisedVolume
- /gate/Voxel/geometry/setHUToMaterialFile MaterialDB/HU2mat_CylindericalPhanom.txt
- /gate/Voxel/geometry/setImage /Phantoms/CylindericalPhantom_voxel.mhd

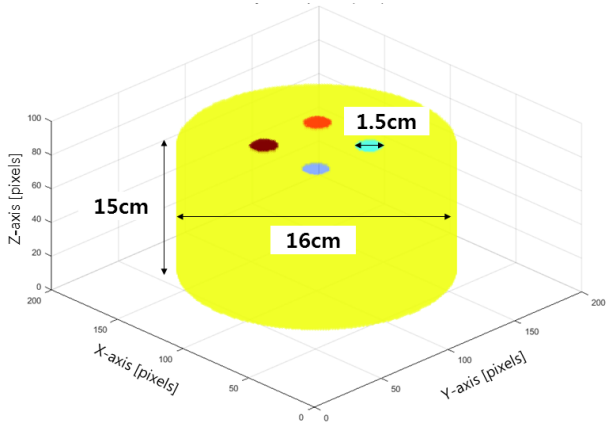
- # HandsOn #1
- # Set material database
- #/gate/geometry/setMaterialDatabse ./MaterialDB/GateMaterials.db
- #/gate/geometry/setMaterialDatabse ./MaterialDB/patient-HUmaterials.db
- /gate/geometry/setMaterialDatabse ./MaterialDB/GateMaterials_modified.db

Matlab to Gate



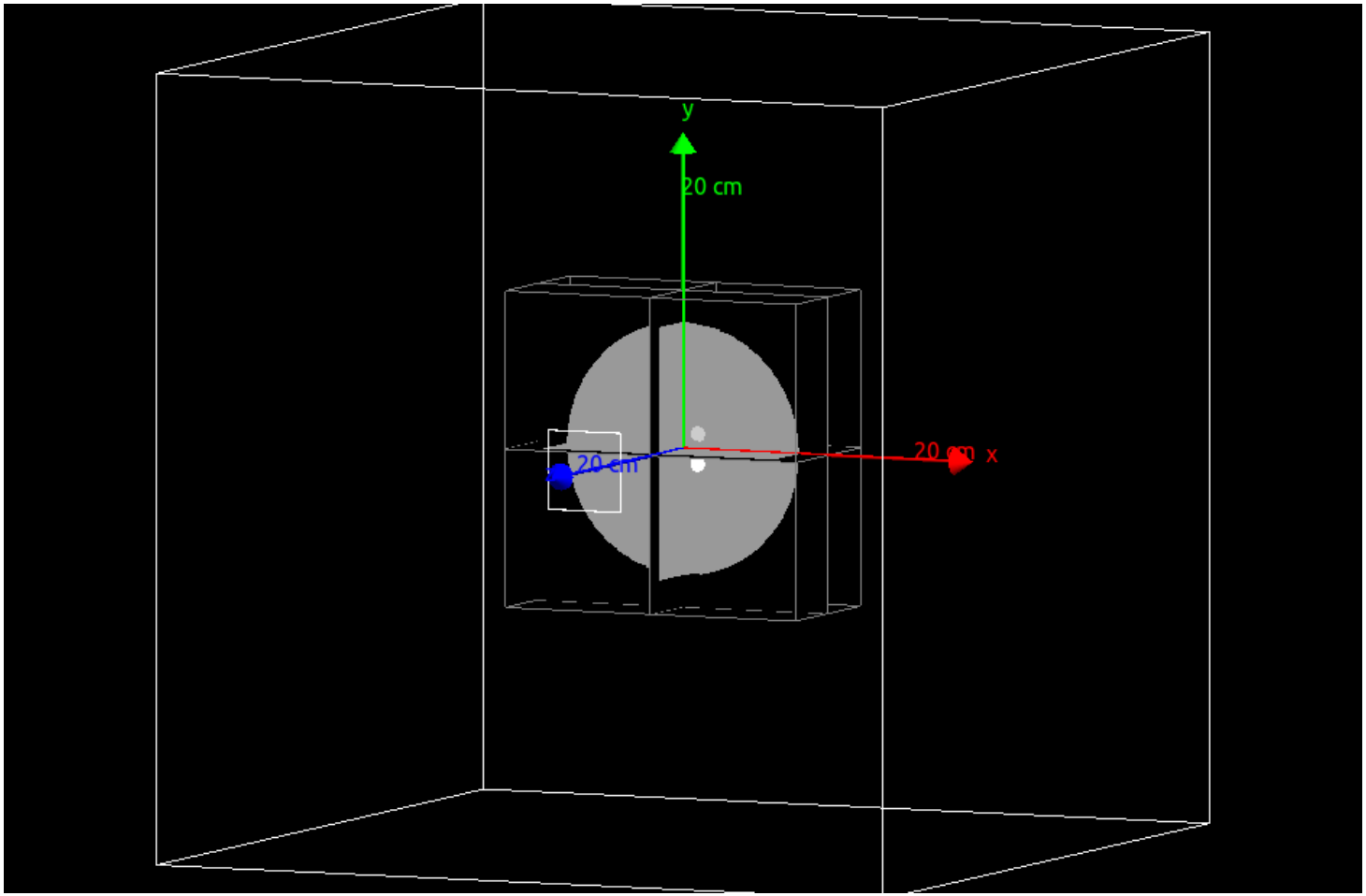


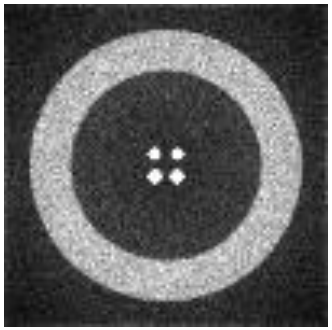




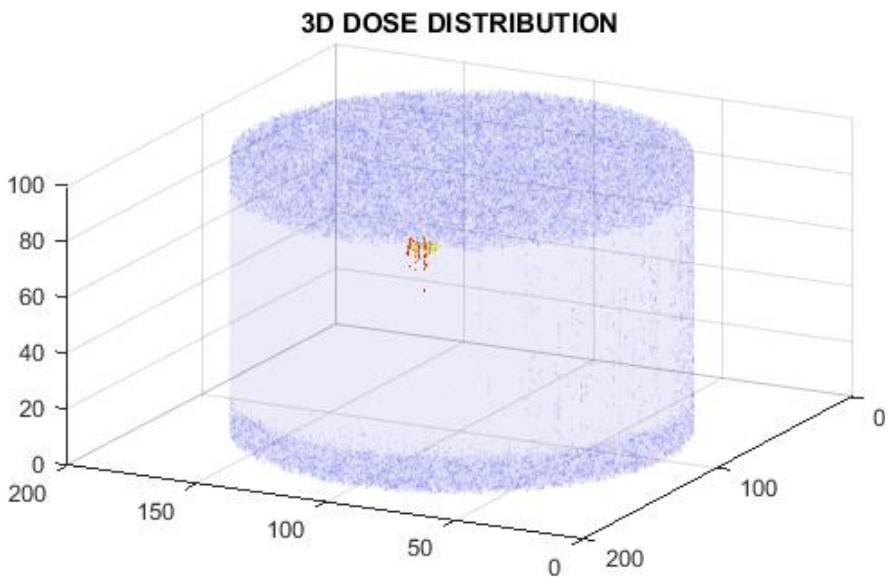
w/ Eunvin Joo, Kyuseok Kim

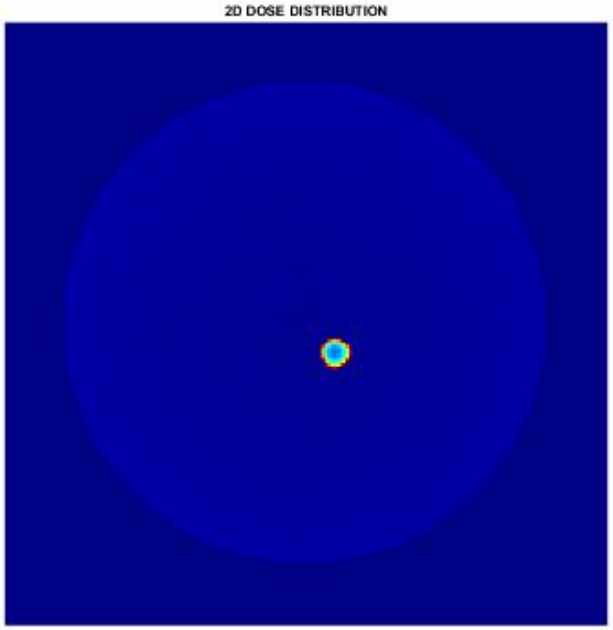
Matlab to Gate



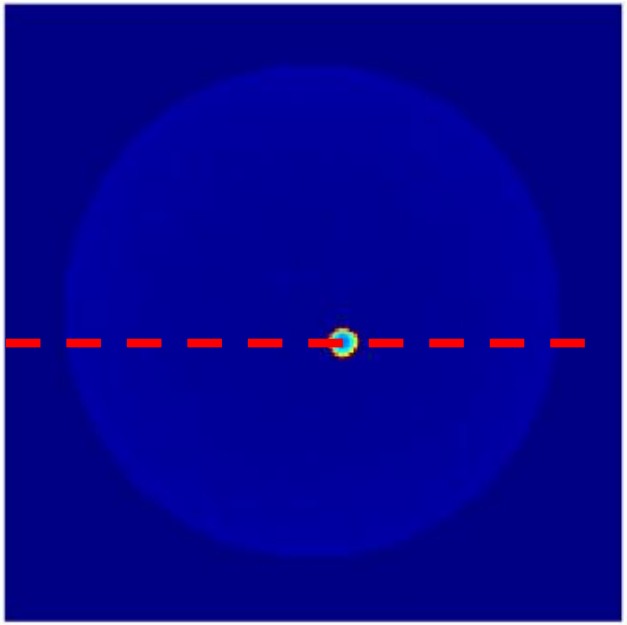


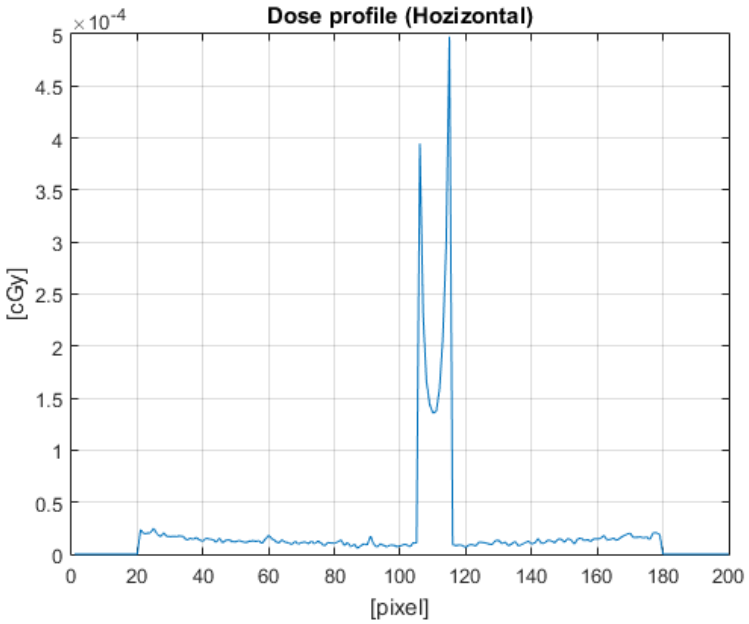
Result (CT imaging dose)





Result (CT imaging dose)





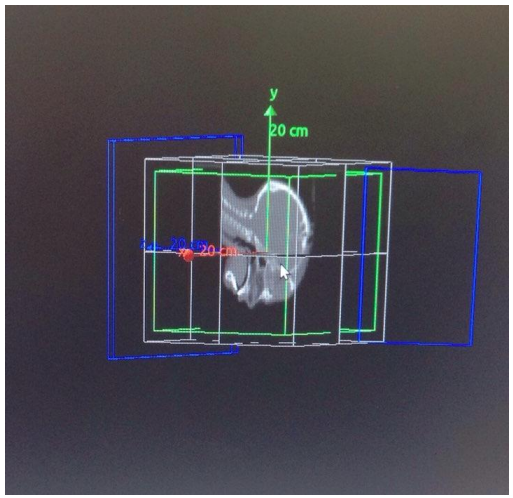
```
# Patient phantom
/gate/CT/daughters/name                     patient
/gate/CT/daughters/insert                   ImageNestedParametrisedVolume
#/gate/patient/geometry/setHUToMaterialFile  data/HU2mat.txt
#/gate/patient/geometry/setImage             data/PhantomSlice10px.mha
/gate/patient/geometry/setHUToMaterialFile  data/HU2mat.txt
/gate/patient/geometry/setImage             data/CylindericalPhantom_voxel.mhd

#=====================================================
# BEAM
#=====================================================

/gate/source/addSource xraygun       gps
/gate/source/xraygun/gps/particle    gamma
/gate/source/xraygun/gps/energytype  Mono
/gate/source/xraygun/gps/ene/mono    80 keV
/gate/source/xraygun/gps/centre      293.5 0. 0. mm
/gate/source/xraygun/gps/direction   -1 0 0
/gate/source/xraygun/gps/type        Plane
/gate/source/xraygun/gps/shape       Rectangle
/gate/source/xraygun/gps/halfx       50 mm
/gate/source/xraygun/gps/halfy       100 mm
/gate/source/xraygun/gps/pos/rot1    0 0 1
/gate/source/xraygun/gps/pos/rot2    0 1 0

#=====================================================
# PHYSICS
#=====================================================

/gate/physics/addPhysicsList            emstandard_opt3

/gate/physics/Gamma/SetCutInRegion      world 10 mm
/gate/physics/Electron/SetCutInRegion   world 10 mm

/gate/physics/Gamma/SetCutInRegion      patient 1 mm
/gate/physics/Electron/SetCutInRegion   patient 1 mm

#=====================================================
# DETECTORS
#=====================================================

/gate/actor/addActor SimulationStatisticActor SSA
/gate/actor/SSA/save output/SSA.txt

/control/execute     mac/DAVW.mac # DoseActors with VolumeWeighting algorithm
/control/execute     mac/DAMW.mac # DoseActors with MassWeighting algorithm
```

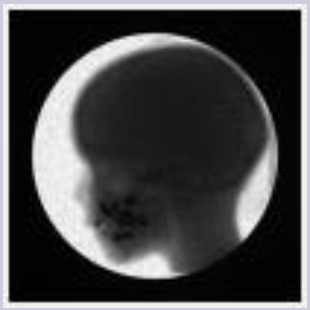
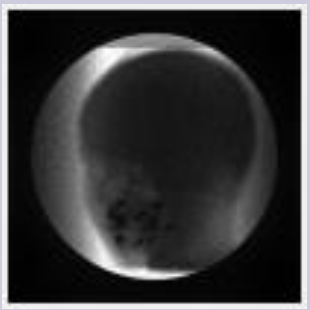
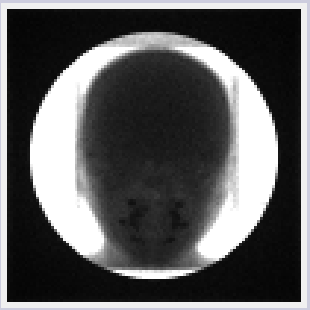
- Archive → https://github.com/wjcheon/CTDI_CTDose_Gate/blob/master/mac/main.mac

CBCT Modeling with GATE using GPGPU

- X-ray source : Real X-ray tube Spectrum
- Detector : scintillation based detector.
- Phantom
  - Phantom defined in GATE
  - Voxelized phantom: Dicom (111 X 111 X 126)
- Computation time
  - NVIDIA GTX-630 (number of cuda cores = 96) : 8 min
  - NVIDIA GTX TITAN X (number of cuda cores = 3072)
  - Inter i5 : 1 hour (about 7 times than GTX-630)

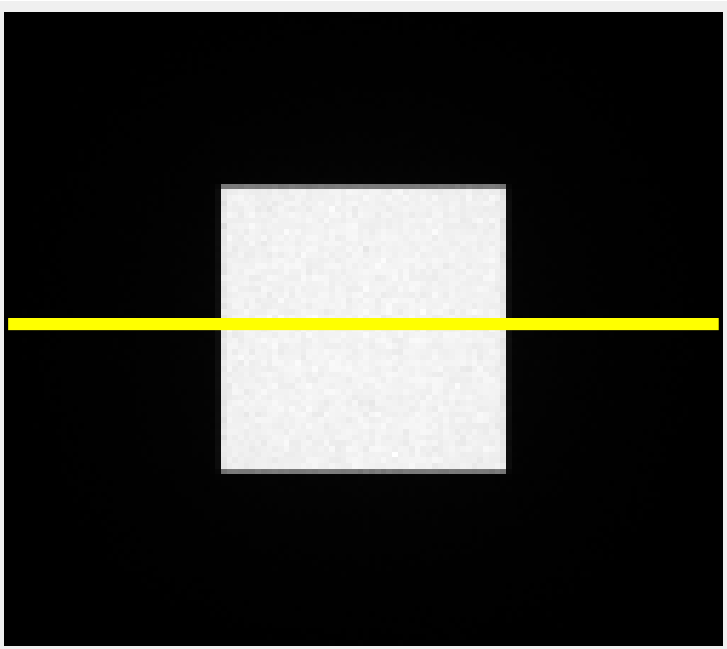
Result



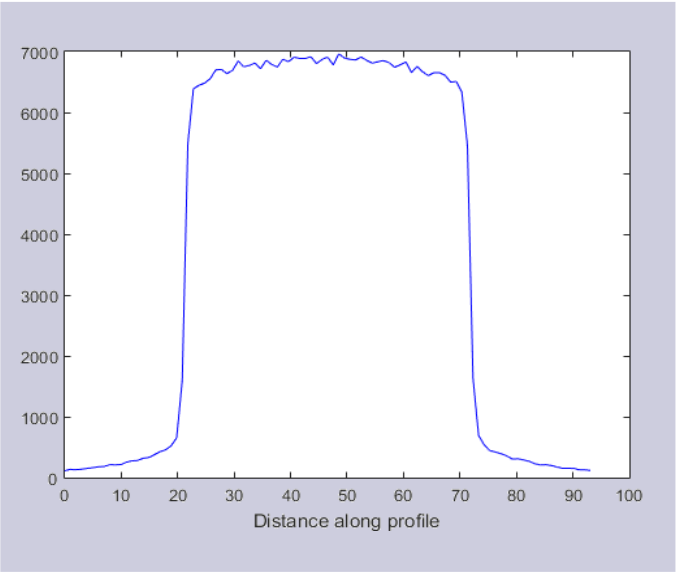
0 degree	45 degree	90 degree
		

LINAC with GATE using GPGPU

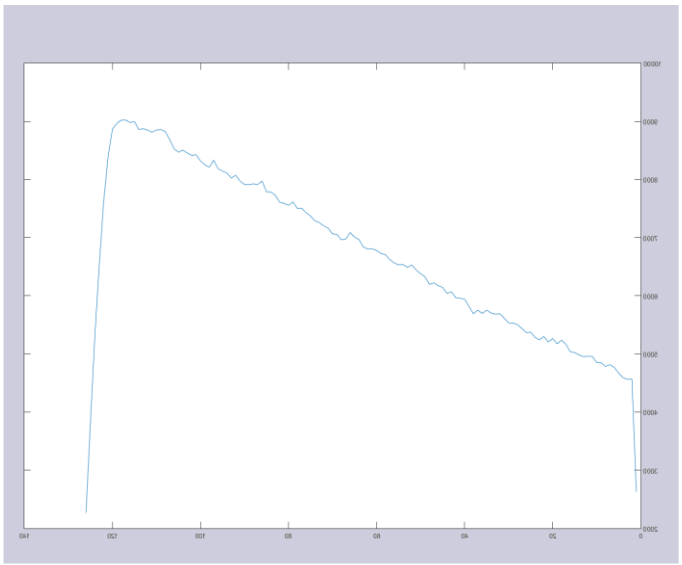
- X-ray source : 3.0 MeV (Mono energy)
- Detector : Voxelized phantom (water)
- Phantom
  - Voxelized phantom
- Computation time
  - NVIDIA GTX-630 (number of cuda cores = 96)
- Result
  - 3D dose distribution (100x100x100)



Transverse dose profile



Percent depth dose (PDD)



Thank You!

2017.06.01.

Wonjoong Cheon, PhD Candidate

Medical Physics Lab, SungKyunKwan University

IV. Install the GATE

Installing GATE in linux

- 필수 설치 소프트웨어
  - Geant4 10.2 (including the embedded CLHEP)
  - GATE V7.2
  - Users can also used the external CLHEP 2.3.1.1

- Output 관리를 위한 옵션 패키지
  - ROOT
  - ECAT
  - LMF

CLHEP 설치

- 다운로드 주소 → http://proj-clhep.web.cern.ch/proj-clhep/DISTRIBUTION
  - GATE V7.2 와 GEANT4 ver10.2 에 대한 CLHEP 권장 버전은 CLHEP 2.3.1.1

- 다운로드 파일을 압축 해제
  - tar -xzf clhep-2.3.1.1.tgz

- 동일한 디렉토리 내에서 CLHEP 를 설치하고 빌드하기 위해 두개의 디렉토리 생성
  - mkdir 2.3.1.1-build
  - mkdir 2.3.1.1-install

- CLHEP 빌드 디렉토리로 이동
  - cd 2.3.1.1-build

압축 해제 명령어: tar –xvzf [압축 해제할 압축 아카이브 이름]

새 디렉토리 생성 명령어: mkdir [옵션] [생성할 디렉토리]

CLHEP 설치

- cmake 명령어와 make 명령어 실행
  - cmake -DCMAKE_INSTALL_PREFIX=/PATH_TO/2.3.1.1-install /PATH_TO/2.3.1.1/CLHEP/
  - make
  - make test
  - make install

- 환경 변수 파일 업데이트

  (1) bash or zsh:
  - export PATH=$PATH:/PATH_TO/2.3.1.1/-install/bin:/PATH_TO/2.3.1.1-install/include
  - export LD_LIBRARY_PATH=$LD_LIBRARY_PATH:/PATH_TO/2.3.1.1-install/lib

  (2) [t]csh:
  - setenv PATH ${PATH}:/PATH_TO/2.3.1.1/-install/bin:/PATH_TO/2.3.1.1-install/include
  - setenv LD_LIBRARY_PATH ${LD_LIBRARY_PATH}:/PATH_TO/2.3.1.1-install/lib

ROOT 설치

- 다운로드 주소 → http://root.cern.ch/drupal
- 하드웨어 구조에 따른 ROOT 버전 선택 및 다운로드 파일 압축해제
  (1) 64 bits:
  - tar -xzf root_v5.XX.XX.Linux-slc5_amd64-gcc4.3.tar.gz

  (2) 32 bits:
  - tar -xzf root_v5.XX.XX.Linux-slc5-gcc4.3.tar.gz
- ROOT 디렉토리 이동
  - mv root root_v5.XX
- 환경에 따라 ROOT 를 다음과 같이 소스 할 것.
  (1) bash or zsh:
  - source /PATH_TO/root_v5.XX/bin/thisroot.sh

  (2) [t]csh:
  - source /PATH_TO/root_v5.XX/bin/thisroot.csh

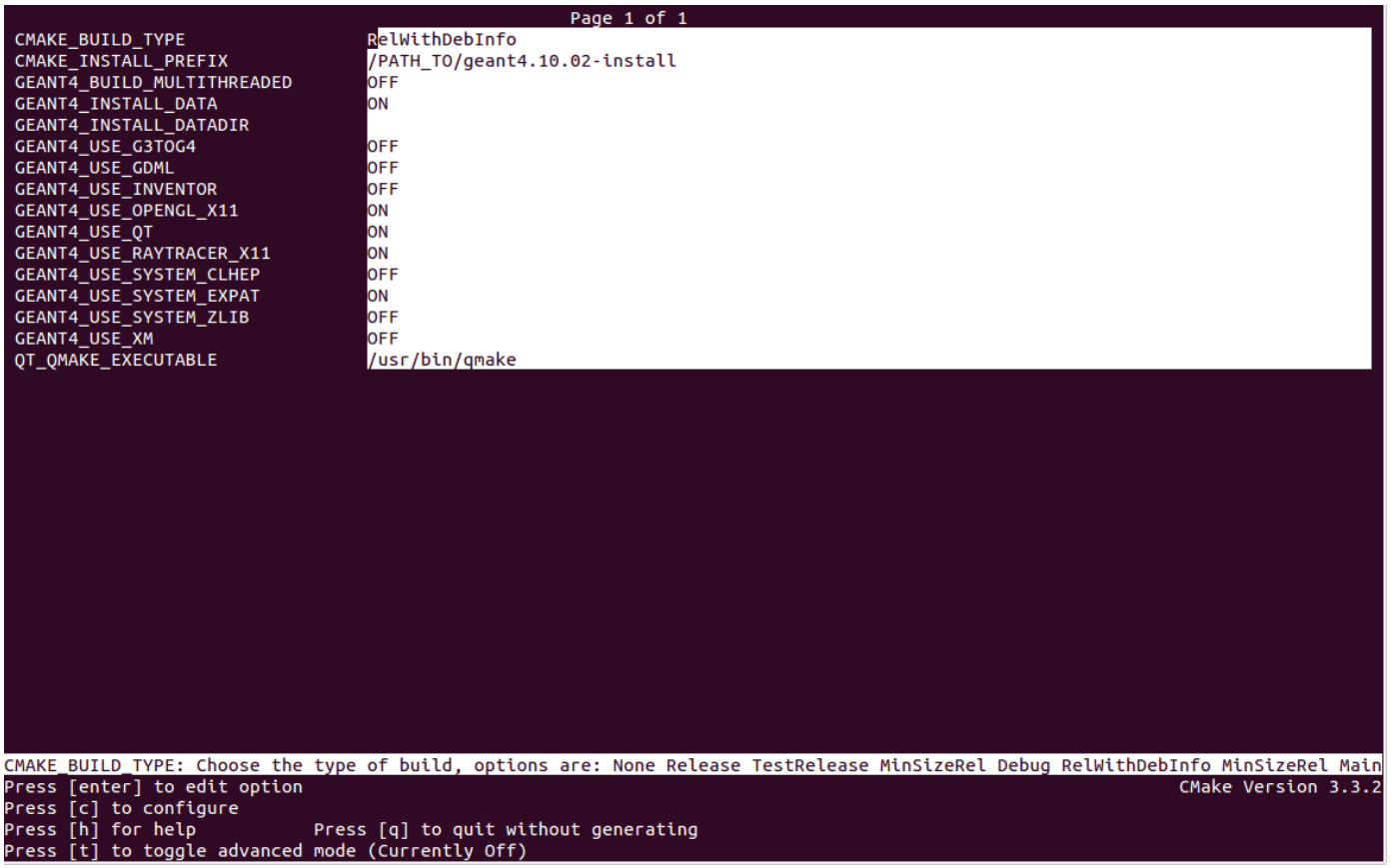
이동 명령어: mv [옵션] [옮길 대상] [옮길 위치]

Geant4 설치

- 다운로드 주소 → http://geant4.web.cern.ch/geant4/support/download.shtml
- 압축 해제
  - tar -xzf geant4.10.02.tar.gz
- 동일한 디렉토리에서 GEANT4를 빌드하고 설치하기 위해 두개의 디렉토리 생성
  - mkdir geant4.10.02-build
  - mkdir geant4.10.02-install
- GEANT4 빌드 디렉토리로 이동
  - cd geant4.10.02-build
- ccmake 실행
  - ccmake ../geant4.10.02

Geant4 설치

- 다음 화면이 나타나며, 다양한 옵션을 구성할 수 있음.
- QT 및 OPENGL 은 사용자가 수행하려는 작업에 따라 선택사항임.



Geant4 설치

- GATE는 아직 멀티스레드(Multi-thread) 모드에서 실행할 수 없으므로, GEANT4_BUILD_MULTITHREADED 를 비활성화 (off)
- GEANT4_INSTALL_DATA 및 GEANT4_USE_SYSTEM_CLHEP 은 필수 사항이므로 활성화 (on)
- 'c'를 눌러 구성하고(configure), 'g'를 눌러 컴파일 환경을 생성 (generate)

- 이 단계가 끝나면, 자동으로 prompt terminal 로 돌아온 다음, 컴파일을 시작할 수 있음.
  - make -jN (N is the number of processor(s) in your PC)
  - make install
- 환경 변수 파일 업데이트

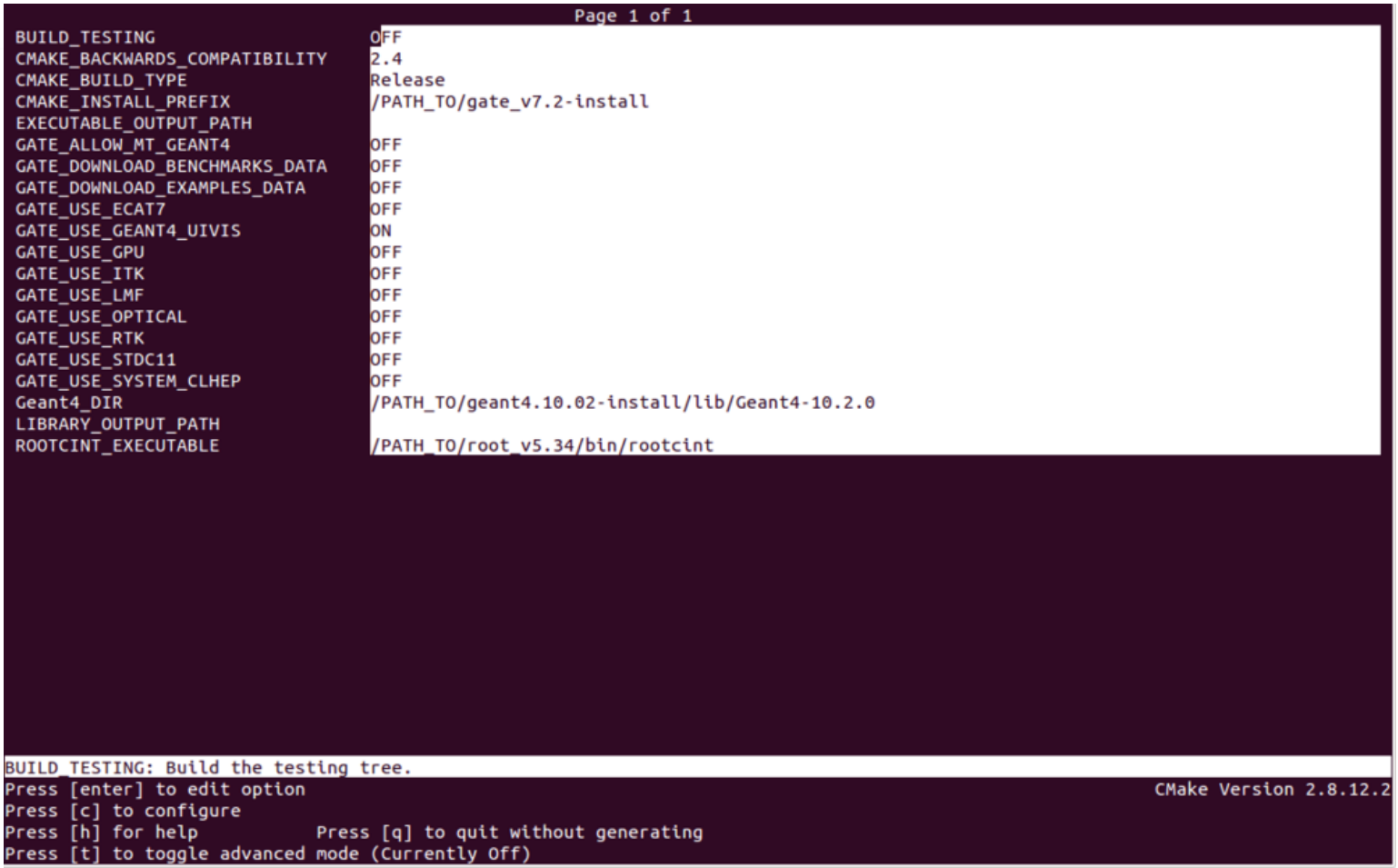
  (1) bash or zsh:
  - source /PATH_TO/geant4.10.02-install/bin/geant4.sh

  (2) [t]csh:
  - source /PATH_TO/geant4.10.02-install/bin/geant4.csh

GATE V7.2 설치

- 다운로드 주소 → http://www.opengatecollaboration.org/GATE72
- 압축 해제
  - tar -xzf gate_v7.2.tar.gz
- 동일한 디렉토리에서 GEANT4를 빌드하고 설치하기 위해 두개의 디렉토리 생성
  - mkdir gate_v7.2-build
  - mkdir gate_v7.2-install
- GATE 빌드 디렉토리로 이동
  - cd gate_v7.2-build
- ccmake 실행
  - ccmake ../gate_v7.2

GATE V7.2 설치



GATE V7.2 설치

<환경 변수 정보>

- GATE_DOWNLOAD_BENCHMARKS_DATA OFF: by default, set to ON if you want to download them
- GATE_DOWNLOAD_EXAMPLES_DATA OFF: by default, set to ON if you want to download them
- GATE_USE_ECAT7 OFF: by default, set to ON if you want to use this library
- GATE_USE_GPU OFF: by default, set to ON if you want to use GPU modules
- GATE_USE_LMF OFF: by default, set to ON if you want to use this library
- GATE_USE_OPTICAL OFF: by default, set to ON if you want to perform simulation for optical imaging applications
- GEANT4_USE_SYSTEM_CLHEP OFF: by default, set to ON if you want to use an external CLHEP version (2.2.0.4)

- 'c'를 눌러 구성하고(configure), 'g'를 눌러 컴파일 환경을 생성 (generate)
  - make -jN (N is the number of processor(s) in your PC)
  - make install

- 환경 변수 파일 업데이트

  (1) bash or zsh:
  - export PATH=$PATH:/PATH_TO/gate_v7.2-install/bin

  (2) [t]csh:
  - setenv PATH ${PATH}:$/PATH_TO/gate_v7.2-install/bin

GATE V7.2 설치

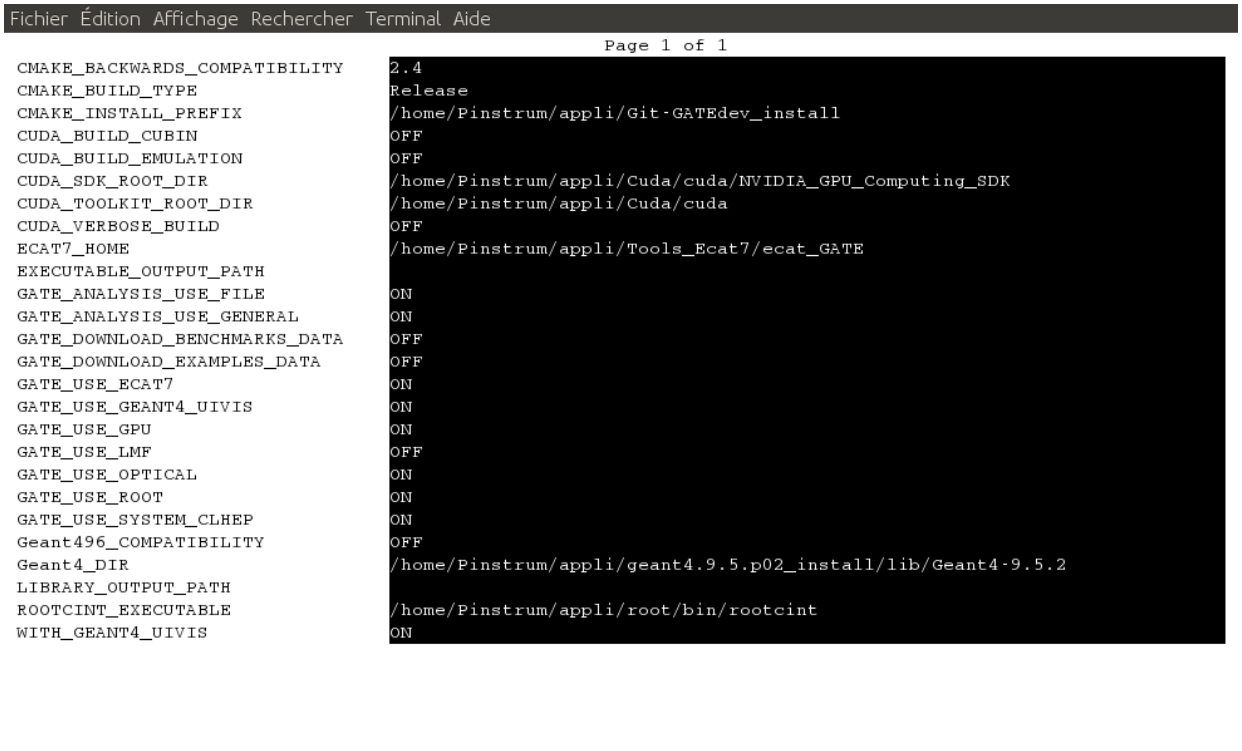
- 환경 설정 및 GATE 시작
  - 전체 GATE 시뮬레이션을 수행하는 데 필수적인 모든 환경변수를 설정하려면 your_file.bashrc (or .cshrc) 파일을 구성하는 것이 좋다. 이 파일은 다음과 같이 정의.
- bash or zsh
  - source /PATH_TO/root_v5.XX/bin/thisroot.sh
  - source /PATH_TO/geant4.10.02-install/bin/geant4.sh
  - export PATH=$PATH:/PATH_TO/gate_v7.2-install/bin
- 외부 CLHEP 라이브러리를 사용할 경우,
  - export PATH=$PATH:/PATH_TO/2.3.1.1/CLHEP/bin
  - export LD_LIBRARY_PATH=$LD_LIBRARY_PATH:/PATH_TO/2.3.1.1/CLHEP/lib
- [t]csh
  - source /PATH_TO/root_v5.XX/bin/thisroot.csh
  - source /PATH_TO/geant4.10.02-install/bin/geant4.csh
  - setenv PATH ${PATH}:$/PATH_TO/gate_v7.2-install/bin
- 외부 CLHEP 라이브러리를 사용할 경우
  - setenv PATH ${PATH}:/PATH_TO/2.3.1.1/CLHEP/bin
  - setenv LD_LIBRARY_PATH ${LD_LIBRARY_PATH}:/PATH_TO/2.3.1.1/CLHEP/lib

GATE V7.2 실행

- GATE 세션을 시작하기전
  - source your_file.bashrc
- GATE 실행 명령어
  - Gate

GPU & CUDA 툴 (optional)

- NVIDIA와 GPU 컴퓨팅 SDK가 제공하는 CUDA 툴킷인 2 개의 패키지를 다운로드
  → http://doc.ubuntu-fr.org/cuda
- ccmake를 사용하여 GATE를 구성하는 동안 GATE_USE_GPU 변수를 ON으로 설정하고 CUDA_SDK_ROOT_DIR 및 CUDA_TOOLKIT_ROOT_DIR에 대한 올바른 경로를 지정해야 함.



Reference

- GATE website: http://www.opengatecollaboration.org
- GATE user mailing: gate-users@lists.opengatecollaboration.org
- Installing GATE : http://opengatecollaboration.org/InstallingGATE
- GATE documentation: http://opengatecollaboration.org/Documentation
- Lydia MAIGNE, GATE Monte Carlo simulation platform, 2011
- D.Lazaro, V.Breton, GATE asimulation platform for nuclear medicine based on GEANT4

Thank You!

2017.06.01.

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